EFFECTS OF ENVIRONMENTAL FACTORS ON NUTRIENTS AND ANTINUTRIENT CONTENTS OF SELECTED LEAFY VEGETABLES

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN AGRONOMY AND SOIL SCIENCE

MAY 1986

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Dedicated to my Father

ACKNOWLEDGMENTS

My thanks go to the members of my dissertation committee, especially to Dr. Goro Uehara and Dr. Bluebell Standal; the staff of the Benchmark Soils Project; the staff of the Department of Agronomy and Soil Science, University of Hawaii; the staff of the East-West Center, especially those at the Environment and Policy Institute; my colleagues and friends in Hawaii and far away; and my family in Thailand, especially my mother. With their unfailing interest, assistance and encouragement, I have completed this work in good spirits.

The sponsorship of the East-West Center and the partial funding of my studies in Hawaii received from the Government of Thailand are gratefully acknowledged.

This dissertation was skillfully typed by Freda Hellinger.

ABSTRACT

The purpose of this research was to test the hypothesis that plant composition in general, and plant antinutrient content in particular, are affected by environmental factors. To test this hypothesis three crops were grown in four benchmark locations which had been characterized for soils and provided with weather stations to monitor air and soil temperatures, relative humidity, rainfall, solar radiation and wind speed. The four experimental sites represented four soil series and two soil families. The Wahiawa and Lahaina soil series identified on sites on the Islands of Oahu and Molokai were members of the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox, whereas, the Niulii and Kukaiau soil series identified on sites in the Kohala and Hamakua districts of the Big Island of Hawaii were members of the thixotropic, isothermic family of Hydric Dystrandepts.

Three test crops were used to test the hypothesis: amaranth (*Amaranthus gangeticus* L.), a crop cultivated for its tender leaves or grain, cassava (*Manihot esculenta* L.), a crop normally cultivated for its starchy tubers, and taro (*Colocasia esculenta* L. (Schott.), a crop normally grown for its underground corms. The leaves of all three crops are consumed by people in the warm tropics. For this reason, the leaves of all three crops were sampled and analyzed to measure the effects of soil and climate variables on oxalate, nitrate , and ionic contents of leaves.

Amaranth experiments were installed at three sites. At each site, irrigated and non-irrigated experiments were conducted. Within each

irrigation experiment, three fertilizer treatments consisting of (1) a basal treatment of lime, N, P, K, bases, and trace nutrients, (2) a N treatment superimposed on the basal treatment, and (3) a P treatment superimposed on the basal treatment, were arranged in a randomized complete block design with three replications. Plant tops were harvested at maturity for chemical analyses.

Cassava leaves were sampled from ongoing experiments at the four experimental sites. Taro leaves were also sampled from ongoing experiments but from only three sites.

Soil and climatic factors significantly influenced the chemical compositions of crops. These effects differed for each crop. Nitrogen plays an important role in controlling the synthesis of oxalate and the accumulation of nitrate in amaranth. The highly variable oxalate and nitrate contents in plants grown in environmentally different sites were, to a large extent, due to different soil N contents.

Virtually all oxalate in cassava was in the form of calcium oxalate, so that tissue Ca content was an important factor in oxalate formation.

In taro, K appeared to be the key factor accounting for the difference in oxalate content among sites.

It was concluded from the results of this study that plant compositions can be controlled by management of the environment and crop selection. It follows from this conclusion that the nutritional quality of food crops can be measurably improved if more research is directed towards achieving this goal.

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(for Appendices)

AIR1, AIRMAX	Maximum air temperature
AIR1SQ	Square of maximum air temperature
AIR2, AIRMIN	Minimum air temperature
AIR2SQ	Square of minimum air temperature
AIR3, AIRAVE	Average air temperature
AIR3SQ	Square of average air temperature
AIR4	Difference between maximum and minimum air temperature
AIR4SQ	Square of difference between maximum and minimum air temperature
CA	Calcium concentration
CANUPT	Anion uptake
CATUPT	Cation uptake
CAUPT	Calcium uptake
CC-A, C-A	Cation excess
CL	Tissue chloride concentration
CLUPT	Chloride uptake
CNO3	Tissue nitrate concentration
CNO3UPT	Nitrate uptake
DW	Dry weight
K	Tissue potassium concentration
KUPT	Potassium uptake
MG	Tissue magnesium concentration
MGUPT	Magnesium uptake
NA	Tissue sodium concentration
NAUPT	Sodium uptake
NO3N	Tissue nitrate-N concentration
P	Tissue phosphate
PUPT	Phosphate uptake
OX	Total oxalate concentration
OXPRO	Total oxalate production
OX2	Soluble oxalate concentration
OX2PRO	Soluble oxalate production
OX2-3	Sum of soluble and insoluble oxalate concentration
OX2-3PRO	Sum of soluble and insoluble oxalate production
OX3	Insoluble oxalate concentration
OX3PRO	Insoluble oxalate production
RF	Cumulative rainfall
RFSQ	Square of rainfall
RHAVE, RH3	Average relative humidity
RHMAX, RH1	Maximum relative humidity
RHMIN, RH2	Minimum relative humidity
RH4	Difference between maximum and minimum relative humidity

RH1SQ	Square of maximum relative humidity
RH2SQ	Square of minimum relative humidity
RH3SQ	Square of average relative humidity
RH4SQ	Square of the difference between maximum and minimum relative humidity
SOLCA	Soil calcium content
SOLK	Soil potassium content
SOLMG	Soil magnesium content
SOLNA	Soil sodium content
SOLP	Soil phosphate content
SOLTN	Soil total nitrogen content
SOL1	Maximum topsoil temperature
SOL1SQ	Square of maximum topsoil temperature
SOL2	Minimum topsoil temperature
SOL2SQ	Square of minimum topsoil temperature
SOL3	Average topsoil temperature
SOL3SQ	Square of average topsoil temperature
SOL4	Difference between maximum and minimum topsoil temperature
SOL4SQ	Square of the difference between maximum and minimum topsoil temperature
SOL5	Maximum subsoil temperature
SOL5SQ	Square of maximum subsoil temperature
SOL6	Minimum subsoil temperature
SOL6SQ	Square of minimum subsoil temperature
SOL7	Maximum subsoil temperature
SOL7SQ	Square of maximum subsoil temperature
SOL8	Difference between maximum and minimum subsoil temperature
SOL8SQ	Square of the difference between maximum and minimum subsoil temperature
SR	Solar radiation
SRSQ	Square of solar radiation
SSAVE	Average subsoil temperature
SSMAX	Maximum subsoil temperature
SSMIN	Minimum subsoil temperature
SUPT	Sulfate uptake
TN, TOTALN	Tissue total nitrogen
TNUPT	Total nitrogen uptake
TSAVE	Average topsoil temperature
TSMAX	Maximum topsoil temperature
TSMIN	Minimum topsoil temperature
WIND, WSP	Wind speed
WSPSQ	Square of wind speed

CHAPTER I

INTRODUCTION

Agricultural practices and research have been geared toward high production to cope with the high rate of increase in world population. The genetic characteristics that have led to yield improvements were mainly dwarfism and leaf erectness in cereals, such as wheat and rice. These key genetic characteristics gave birth to the green revolution in the 1960s. A third characteristic, photperiod insensitivity, made it easy to fit the short, erect, high yielding varieties into a wide range of environments. Other genetic traits, including resistance to diseases and insects, and tolerance to environmental stress continue to increase yields.

Besides genetic factors, cultural factors are also another means employed by agronomists to increase yields. These include fertilizer application and irrigation.

Low consumer acceptance of several promising high yielding varieties compelled plant breeders to include factors that affect consumer preference into their breeding strategy. In addition, some cultural practice has been implemented with the dual purposes of increasing yield and improving quality with regard to consumer preference, for example, heavy applications of nitrogen fertilizer in order to increase yields and to produce green and succulent produce.

Quality is, therefore, often measured in terms of consumer preference. However, preference alone does not ensure food quality. The nutritional value of an agricultural product is not always apparent to the consumer. More elusive quality factors are the antinutrient and toxic agent contents of food crops. Their effects on the consumer are often slow and insidious.

Food compositions tables are used indiscriminantly to identify and quantify the nutrients present in various foodstuffs, in spite of their knowledge of the high variability in nutrient contents among cultivar of food crops and among similar crops grown in different places. The source of variability could be genetic and/or environmental and cultural. With regard to environmental factors, growers need to know the environmental factors that affect food quality.

This study was based on the hypothesis that variance in nutritional quality of food crops is strongly influenced by cultural and environmental factors.

The type of food crops selected for this study were leafy vegetables because they are important sources of oxalate (an antinutrient) and nitrate (a toxic agent) which are nutritionally significant.

Vegetables are important sources of vitamins and minerals essential for humans and animals. Some of them are also an unconventional source of protein recommended for the tropics where meat is relatively scarce. However, some vegetables, such as amaranth (*Amaranthus* species), cassava leaves (*Manihot* species), taro leaves (*Colocasia* species), purslane (*Portulaca oleracea* L.) and ungchoi (*Ipomoea aquatica*) of the tropics; and spinach (*Spinacea oleracea* L.), rhubarb (*Rheum rhaponicum*), beet (*Beta vulgaris*) of the temperate regions contain high levels of antinutrient oxalate. Oxalate is considered an antinutrient because it can render some mineral nutrients unavailable by binding them to form insoluble salts which are not absorbed by the intestine. Many vegetables also contain high content of nitrate which is a toxic agent to humans and animals.

The main interest in oxalate is its complex formation with calcium (Ca) to form insoluble Ca-oxalate both within plants and the human body. This precludes the utilization of Ca. Furthermore, high level of soluble oxalate and free oxalic acid can combine with Ca from other foods, further reducing Ca availability in diets.

There exist relationships between oxalate and nitrate contents in plants and factors of the agroenvironment. These include soil nutrient status, temperature, soil moisture, and intensity and duration of radiation. Such knowledge has prompted the idea of reducing the content of these two compounds in plants by manipulating agroenvironmental factors. The most widely researched factor is perhaps plant nutrient supply. For example, different forms of nitrogen fertilizers affect the oxalate and nitrate contents in plants differently. While nitrate fertilizer tends to increase oxalate and nitrate contents in plants, ammonium fertilizer tends to decrease them.

Cation-anion balance is a sound concept to explain the presence of oxalate in plants. It was proposed that organic acids (including oxalate) were produced to balance excess cations. In this way, any external factors which can exert influence on the content of cation excess in plants should, in turn, affect oxalate content.

Amaranth, taro and cassava, chosen for this study, contain high levels of oxalate and are widely consumed as vegetables in the tropics. Amaranth is also gaining popularity in the continental U.S. as a leafy vegetable.

This study was undertaken to investigate the effects of agroenvironmental factors on the production of oxalate and nitrate in these tropical vegetables in the hope that the additional knowledge and understanding gained would lead to ideas as to how these factors can be managed to produce high quality vegetables with regard to their contents of oxalate and nitrate. The objectives of this study are, therefore, as follows:

1. To assess the contribution of soil and climate variables to the variance in oxalate and nitrate contents of food crops.

2. To ascertain the relationship between cation-anion balance and the biosynthesis of oxalate.

3. To identify practical measures to control oxalate and nitrate contents of food crops.

CHAPTER II

REVIEW OF LITERATURE

This study draws upon two disciplines: agronomy and human nutrition. Agronomy deals with understanding and manipulating genotype by environment interactions to optimize food production whereas human nutrition deals with understanding and optimizing human health through nutrition. The relationship being considered is primarily between agro-environment and the nutritional quality of food crops. Inferences are made on the relationship between plant, and man to some extent.

Oxalate and nitrate content, as well as the content of other nutrients of leafy vegetables were chosen as plant parameters that may be affected by soil and climatic factors. Oxalate and nitrate were selected for study because they are an antinutrient and a toxic agent, respectively, to humans. They are also present in many leafy vegetables consumed in the tropics. Moreover, earlier studies indicate that there is a definite relationship between plant tissue nitrate content and agroenvironment. Comparable studies on oxalate, on the other hand, are scarce.

The background information forming the basis for this study is presented and includes the relationships among agroenvironmental factors and oxalate and nitrate contents in plants, the mechanism of oxalate synthesis, and the accumulation of oxalate and nitrate in vegetables.

2.1 Antinutirient oxalate and toxic agent nitrate in foods

Antinutrients are chemical substances (natural or synthetic) that can inhibit nutrients from performing their normal functions.

Antinutrients can be divided into 3 groups according to the mechanisms by which they inhibit nutrient function:

1. Those that bind nutrients chemically and make them unavailable for absorption by the digestive system. Examples of antinutrients are oxalate which binds Ca and phytate which binds trace elements, such as Fe, Zn and Cu. These antinutrients lower the nutritional quality of food, with respect to minerals, because the nutritional quality is determined by the proportion of absorbable and utilizable essential elements in a meal (Mertz, 1980; Quarterman, 1973 as cited by Welch and House, 1984).

2. Those that compete with nutrients for intestinal absorption sites.

3. Those that compete with nutrients for biological (enzymic) reaction sites. For example, antivitamins such as isoniazid (a tuberculosis drug), which competes with pyridoxine (vitamin B_6).

Antinutrients that bind nutrients (group 1) do so in the food before it is ingested and/or in the body. Oxalic acid belongs to this group of antinutrients.

Oxalic acid ($H_2C_2O_4$) is a relatively strong dicarboxylic acid. Like other acids, oxalic acid can be converted into salts. This property is important for this study because oxalic acid becomes an antinutrient when it forms insoluble salts with nutrients such as Ca and Mg. Hodgkinson (1977) has described the properties of various oxalate salts in detail. Of particular interest are the oxalate salts of Ca, Mg, K, Na and ammonium (NH_4) that are frequently encountered in plants.

Oxalic acid forms neutral and acid salts with monovalent cations including ammonium. With most divalent cations it forms only one salt. Potassium forms three salts, a neutral and acid salt and a tetraoxalate (Hodgkinson, 1977).

Except for the salts of the alkali metals (Li, Na, K), ammonium, and Fe III, most oxalates are sparingly soluble in water. The most soluble oxalate salt associated with a bivalent metal is magnesium oxalate (MgC_2O_4), and the least soluble among the common oxalates are calcium oxalate (CaC_2O_4) and lead oxalate (PbC_2O_4). All are soluble in strong acids (Hodgkinson, 1977). Knowledge of the solubility of oxalates is important for developing techniques to fractionate oxalates in plants.

Oxalic acid becomes an antinutrient when it forms insoluble salts with Ca and Mg. However, the potential of it becoming an antinutrient is high when it is in the form of free acids or soluble salts. Therefore, assessing food quality with respect to its oxalate contents involves fractionating and identifying the kind of salts and/or free oxalic acid a food contains.

Nitrate (NO_3^-) is considered a toxic agent because even though nitrate itself presents no health hazard to human and animal, its derivatives, namely nitrite (NO_2^-) and nitrosamine, are health hazards. The effects of nitrate on health are discussed in section 2.4.

2.2 Oxalate accumulation in vegetables and other plants and its effects on the health of humans and animals

Oxalate exists in plants mainly as water soluble, acid soluble (water insoluble), and free acid forms. The water soluble forms include sodium-, potassium- and ammonium oxalate, and the water insoluble forms include calcium- and magnesium oxalate. Hodgkinson (1977, p. 130) has reviewed the various forms of oxalate in plants. For example, the oxalate in Begonia semperflorens exists almost entirely as free acid, and sodium salts predominate in Halogeton glomeratus. Potassium salts predominate in Oxalis, Rumex, and several Nigerian vegetables, such as Talmium triangulare (Oke, 1969). Ammonium oxalate appears to be the principal form in the tropical grass, Setaria sphacelata, and calcium oxalate is found in plants such as beet, spinach, and buckwheat. Der Marderosian et al. (1980) discovered that almost half of the oxalate in amaranth is in the soluble form. Singh and Saxena (1972) found both soluble and insoluble forms of oxalate in six leafy vegetables consumed in India (i.e., amaranth [Amaranthus gangeticus L.], bathua [Chenopodium album L.], kharbathua [C. murale L.], purslane [Portulaca oleracea L.], spinach [Spinacea olearacea L.] and beet [Beta vulgaris L.]). High correlations were found between the concentration of soluble oxalate and K and Na, and between insoluble oxalate and the sum of Ca and Mg. Sap pH has been used to identify high oxalate-producing plants, as sap pH correlates well with the form of oxalate (James, 1972, p. 232). Two categories of plants are recognized:

1. Plants such as Oxalis pes-caprae and some species of Rumex, which have a sap pH of about 2 in which case the oxalate anion is present chiefly as the acid oxalate ($HC_2O_4^-$).

2. Plants of some Chenopodiacae, which have a sap pH of about 6 indicating that the oxalate is present chiefly as the oxalate anion ($C_2O_4^{2-}$).

According to James (1972), the oxalate in the first category of plants is present chiefly as potassium acid oxalate, and the oxalate in the second category is present mainly as soluble sodium oxalate and the insoluble calcium and magnesium oxalates.

One of the plants with the highest known oxalate content is _Halogeton glomeratus_ (Chenopodiaceae). This plant contains as much as 30% oxalate on a dry weight basis. Another high oxalate plant is _Oxalis cernua_ (Oxalidiaceae) (Fassett, 1973). In spinach, the total oxalate content ranges on a dry weight basis from 5.42% in savoyed-leaf variety to 9.81% in smooth leaf variety (Kitchen et al., 1964a). Fassett (1973) summarizes oxalate contents in various plants, expressed as percent on a fresh weight basis. The contents range from 0.3-1.2% in spinach, 0.2-1.3% in rhubarb, 0.3-0.9% in beet leaves, 0.3-2.0% in tea and 0.5-0.9% in cocoa. Suvachittanont et al. (1973) determined the oxalic acid content of some vegetables from Thailand and reported oxalic acid contents of 3.3% on a dry weight basis (DW) or 0.4% on a fresh weight basis (FW) for _Amaranthus gangeticus_ Linn. and 0.6% DW or 0.1% FW for cassava leaves. According to Standal (1982), the oxalate content of taro leaf (_Colocasia esculenta_ var. Bun-long) was 0.5% FW.

The oxalate content of plants is generally higher in the leaves than the stalk (Fassett, 1973), as has been demonstrated in amaranth (Der Marderosian et al., 1980), taro (Standal, 1983), and spinach (Kitchen and Burns, 1965). Kitchen and Burns (1965) found only trace amounts of oxalic acid in spinach seed. They stated that oxalate concentration decreased with increasing distance from the leaves, which is assumed to be the site of oxalate production.

The probable detrimental effects of oxalic acid and oxalate on human health are as follows:

1. According to Suvachittanont et al. (1973) ingestion of dilute oxalic acid solution produces little gastrointestinal distress but may cause weakness, muscular twitchings, sometimes convulsions, coma or death.

2. It has also been suggested that oxalic acid might play a role in cardiovascular disease (Anderson et al., 1971).

3. A harmful effect, particularly in relation to calcium utilization, has been demonstrated for dietary oxalate. For example, Pingle and Ramasastri (1978) showed that in humans, the availability of Ca from a diet of amaranth leaves was very low relative to that from milk. In addition, the intake of amaranth leaves together with milk adversely affected the absorption of milk Ca.

4. Excessive intake of oxalates in the diet is an etiological factor for the formation of renal and urinary calculi. Renal and urinary calculi are known to contain oxalate, especially Ca oxalate. In an area in Thailand where urinary bladder stone disease is endemic, local vegetables and forest plants commonly consumed by villagers of all ages contained very high levels of oxalic acid (Valyasevi and Dhanamitta, 1974). Oxalate consumption in Rajasthan, India has been suggested as a cause of the incidence of renal calculi (Singh et al., 1972).

The different forms of oxalate have different implications to human nutrition. Insoluble calcium oxalate precludes the utilization of calcium in the intestine. Soluble oxalate and free oxalic acid can combine with calcium from other foods and thus reduce calcium availability. Hodgkinson has cited work which shows that oxalic acid and soluble oxalates interfere with the intestinal absorption of calcium and that calcium oxalate is poorly utilized (Hodgkinson, 1977, p. 207).

Oxalate poisoning in animals, especially ruminant animals, is well-documented. There is ample evidence that many pasture plants and weeds containing oxalate, are poisonous to animals. James (1972) gave a thorough and comprehensive review of incidences of oxalate poisoning in animals with an emphasis on oxalate toxicosis. According to James (1972), oxalate poisoning in livestock results primarily from the ingestion of plants. She gave examples of plants that contain dangerously high levels of oxalate (10% or more anhydrous oxalic acid on a dry weight basis) including Halogeton glomeeratus, greasewood (Sarcobatus vermiculatus) and sugar beet (Beta vulgaris) of the Chenopodiaceae family; soursobs (Oxalis pes-caprae) and the sorrels of the Oxalidaceae family; and certain Rumex species, and docks of the Polygonaceae family. Grasses also produce oxalate, but they do so at a lower level than the previously listed forbs and shrubs. In the tropical grass Setaria (Setaria sphacelata), in which oxalate poisoning of grazing animals has been reported, the oxalate contents of some varieties reach values as high as 4-5% on a dry weight basis (Jones et al., 1970). Pigweed (Amaranthus retroflexus) leaf contains oxalate content as high as 12-30% on a dry weight basis (Marshall et al., 1967). Poisoning and sometimes death have been reported in swine (Osweiler et al., 1969 as cited by James, 1972) and cattle (Brown, 1974; Stuart et al., 1975) ingesting this plant.

According to James (1972), most oxalate-producing plants are palatable to livestock, and therefore the husbandry of ruminants with access to these plants becomes critical. The extent of damage to livestock can be extensive. A case where 1200 sheep were poisoned, of which 100-800 died, has been reported. Deaths in numbers less than a hundred are common (James, 1972).

James (1972) has described in detail the symptoms of oxalate poisoning and its accompanying pathological changes. There appears little doubt that if intake of oxalate from forage exceeds the capacity of rumen decomposition, sheep, cattle, swine and horses may develop serious (acute and chronic) symptoms accompanied by deposition of calcium oxalate crystals in various tissues. Furthermore, she pointed out that the response of animals to oxalate intoxication varied with animal species as well as with species of plant consumed. This is an indication that the kind and amount of oxalate found in plants affect the health of consumers.

2.3 Factors affecting oxalate contents in plants

Factors such as soil fertility, light intensity, season, temperature, plant age, and genotype influence the oxalate content of plants. These factors can be grouped into broader categories--soil, agroclimate, genetic make up of plants, and stage of growth.

2.3.1 The concept of cation-anion balance

The concept of cation-anion balance is the most widely used explanation for the variation in the organic acid concentration of plants (Kirkby and Mengel, 1967; Kirkby, 1969; Ismandji and Dijkshoorn, 1971; Breteler, 1973; Dijkshoorn, 1973; Nelson and Selby, 1974; Kirkby and Knight, 1977; Peck et al., 1980; Israel and Jackson, 1982). The concept is based on the assumption that in higher plants the sum of cation including Ca, Mg, K and Na (denoted by C) and expressed as cmol

kg^{-1} (me 100 g^{-1}) of dry weight minus the sum of inorganic anion concentrations, including NO_3^-, $H_2PO_4^-$, SO_4^{2-}, and Cl^- (denoted by A), represents the cations excess (C-A) that should occur as the salts of organic acids (Dijkshoorn, 1962).

The following is an example to illustrate this concept:

The results of plant analyses show that

- Sum of cations (Ca^{2+}+Mg^{2+}+K^++Na^+) = 180 cmol kg^{-1}
- Sum of unassimilated anion concentrations ($H_2PO_4^-$+SO_4^{2-}+NO_3^-+Cl^-) = 70 cmol kg^{-1}
- Excess cations = 180 - 70 = 110 cmol kg^{-1}
- Sum of organic anion concentrations (e.g. malate, citrate, fumarate, succinate, malonate, quinate, oxalate and polyuronate = 110 cmol kg^{-1}

In some plants, such as those in the family Chenopodiaceae and some tropical grasses, oxalic acid predominates (Dijkshoorn, 1973; Zindler-Frank, 1976), but in most other plant species malic acid dominates (Dijkshoorn, 1973). About 10-20% of (C-A) is polyuronic acid in cell walls and the remainder being other organic acids (Dijkshoorn, 1973).

2.3.2 Soil ionic environments

Soil fertility exerts some effects on oxalate levels of some plants. High soil fertility associated with high soil carbon, nitrogen, available phosphorus, and potassium is associated with high total oxalate in *Amaranthus* and *Basella* (Schmidt et al., 1971). However, differences among species were much greater than differences due to soil fertility.

Other studies have shown the existence of a relationship between calcium and oxalate contents in plants. Rasmussen and Smith (1961) demonstrated a positive correlation between calcium and oxalic acid in Valencia orange leaves. Olsen (1939) suggested that calcium absorption from the soil is related to oxalic acid production in plants. Brumagen and Hiatt (1966) found that oxalate interfered with calcium translocation and utilization in tobacco plants. They measured more oxalic acid in tobacco varieties that were susceptible to calcium deficiency than in non-susceptible varieties. De Kock et al. (1973) studied the effect of oxalate on the absorption of calcium in *Lemna gibba* L. and demonstrated that Ca uptake and oxalate production were stimulated in each other's presence. They suggested that oxalate acts as a carrier for calcium in the absorption process and is subsequently reduced and condensed with coenzyme A to form malic acid. However, some contradictory evidence has been presented by Osmond (1967), who found that in *Atriplex* (Australian salt bush), calcium absorption and oxalate synthesis varied independently, and that oxalate content was generally correlated with a high cation content as a whole rather than with the calcium alone.

Since liming is a common practice in crop production, further studies on the effects of liming on oxalate content in plants should indicate if certain modification in this practice needs to be made to obtain a desirable crop quality with regard to oxalate content.

Smith (1972) showed that a positive correlation exists between potassium applied and oxalate level in the grass *Setaria sphacelata*. Moreover, significant relationships between oxalic acid and cation excess values were shown suggesting that accumulation of oxalic acid was the result of high application rates of potassium, which in turn affected the cation excess.

Soil pH affects the level of oxalic acid. Wadleigh and Shive (1939) found that the total organic acid content, including oxalic acid, increased in corn plants as substrate pH was increased.

Nitrogen in various forms exert profound effects on oxalate contents in plants. The forms of nitrogen fertilizers investigated were mainly ammonium and nitrate (e.g., Kirkby, 1968; Kirkby and Knight, 1977), and in some investigations, urea (e.g., Kirkby and Mengel, 1967; Vityakon, 1979). Generally, nitrate resulted in a higher oxalate content than ammonium. This observation has been explained in terms of cation-anion balance. In general, nitrate fertilizer results in higher cation excess than ammonium. Therefore, one recommended method of reducing the oxalate content in plants is to stabilize ammoniacal fertilizers with a nitrification inhibitor.

The effects of phosphorus and zinc fertilizers on oxalate contents of plants have been investigated by Peck et al. (1980). In table beets, which is a well-known oxalate accumulator, there was a clear relationship between increasing rates of phosphorus application and reduced oxalate levels in blades, petioles, and roots. These workers suggested that phosphorus application lowered oxalic acid by reducing cation concentrations and also by lowering cation excess. Zinc fertilizer did not appear to have any significant effects on oxalic acid in table beets. They discussed the implication of these results from a human nutrition point of view and speculated that phosphorus fertilization of table beets might result in more available calcium.

2.3.3 Environmental factors

Research on environmental factors affecting plant chemical composition is sparse and sometimes contradictory. Singh and Saxena (1972) stated that environmental factors, such as light intensity, season and temperature influenced the synthesis of oxalic acid in plants. Eheart and Massey (1962) conducted a greenhouse experiment to study the effects of environmental factors on the oxalate content of spinach and concluded that plant variety was the only factor that had any significant effect on oxalic acid content. Light intensity, soil moisture, and all interactions did not affect the oxalate content of spinach.

Kitchen et al. (1964b) found that high temperatures decreased oxalates in spinach leaves and postulated that at high temperatures more oxalic acid was used as a respiratory substrate. Gnedkov (1963 as cited by Singh and Saxena, 1972) observed an increase in oxalic acid concentration in some succulent plants maintained in the dark at a low temperature.

The effect of soil moisture on organic acid content in plants was clearly demonstrated in tomato fruits by Lee and Sayre (1946). Citric acid contents were lower in tomatoes grown on wet soils than on dry soils.

2.3.4 Stage of growth or maturity

The literature presents contradictory conclusions on the effect of stage of growth or maturity on the level of oxalate in plants. Kitchen and Burns (1965) observed that both total and soluble oxalates in spinach decreased with age. However, some other scientists reported increases in oxalic acid contents in spinach with the development of the plant (e.g., De Vilmorin and Bilques, 1957; Doesburg and Sweede, 1948 as cited by Kitchen and Burns, 1965). Der Marderosian et al. (1980) demonstrated that oxalate levels in chard, spinach and amaranth tended to increase with plant age. The same trend was also found by Singh and Saxena (1972) in the leaves of six leafy vegetables including amaranth (Amaranthus gangeticus L.), bathua (Chenopodium album L.), kharbathua (C. murale L.), purslane (Portulaca oleracea L.), spinach (Spinacea olearacea L.) and beet (Beta vulgaris L.). Furthermore, the fractions of soluble and insoluble oxalate increased in leaves and decreased in stems with amaranth age. However, Kitchen and Burns (1965) reasoned that the discrepancy was due to a combination of growth stage and season.

2.3.5 Plant genetics

Eheart and Massey (1962) reported significant varietal differences in the oxalate content of spinach even though the range in oxalate content of 12 varieties was only 10.30-11.38% on a dry weight basis. Kitchen et al. (1964a) related the oxalate contents of different spinach varieties according to leaf morphology. Total oxalate content ranged from 5.42% on a dry weight basis in savoyed-leaf varieties to 9.81% on a dry weight basis in smooth-leaf varieties.

Different varieties of the tropical grass, Setaria sphacelata, also contain different levels of oxalate. For example, the Kazungula and Bua River cultivars have 5.0% and 4.1% total oxalate respectively on a dry weight basis (Jones et al., 1970). Amaranth varieties exhibit differences in oxalate content as shown by Der Marderosian et al. (1980). These varietal and species differences offer a basis for selection and breeding work to lower oxalate contents in food crops.

2.4 Nitrate accumulation in vegetables and its effects on human and animal health

Many plant species accumulate nitrate if nitrate is supplied in excess of N requirement. Nitrate levels in plants cannot be measurably reduced without reducing yields (Lorenz, 1978). Nitrate accumulates in plants when uptake rate exceeds reduction and assimilation rates. Such plant nitrate represents a major source of nitrate-N in human diets (Mills et al., 1976). Vegetables such as beets (*Beta vulgaris* L.), spinach (*Spinacea oleracea* L.), broccoli, celery (*Apium graveolens*), lettuce (*Lactuca sativa* L.), radishes (*Raphanus sativus* L.), kale (*Brassica oleracea*), mustard greens (*Brassica juncea*), collard (*Brassica oleracea* var. acephala) (Table 2.1) and *Amaranthus* species (Table 2.2) may accumulate large quantities of nitrate.

Nitrate distribution is not uniform in the plant. In general, nitrate levels are highest in petioles and stems, moderate in leaves and roots and very low in fruit and flowers (Maynard and Barker, 1972; Lorenz, 1978).

Levels of nitrate and nitrate derivatives in foods should be considered in evaluating potential health hazards in foods and feeds. Nitrate itself is non-toxic to man and animals, being readily absorbed and excreted, but its derivatives (i.e., nitrite and nitrosamine) are toxic.

Table 2.1

Range of nitrate content of field-grown vegetables purchased in Columbia, Missouri

Crop	Nitrate-N (% dry weight)
Beans	0.04 - 0.25
Beets	0.09 - 0.84
Broccoli	0.01 - 0.09
Brussel sprouts	0.01 - 0.06
Cabbage	0.01 - 0.09
Carrots	0.00 - 0.30
Cauliflower	0.00 - 0.31
Celery	0.11 - 1.12
Corn	0.00 - 1.01
Cucumber	0.00 - 0.16
Endive	0.06 - 0.67
Lettuce	0.02 - 1.06
Parsnip	0.00 - 0.04
Peas	0.00 - 0.02
Radish	0.41 - 1.54
Spinach	0.07 - 0.66
Squash, yellow	0.09 - 0.43
Tomato	0.00 - 0.11

Source: Brown and Smith, 1967 as cited by Lorenz, 1978.

Table 2.2

Nitrate-N contents of the leaves of some *Amaranthus* species

Species	Nitrate-N (% dry weight)
A. blitum	0.21
A. cruentus	0.74
A. dubius	0.27
A. gangeticus	0.36 - 0.90
A. hypochondriacus	0.65

(after Der Marderosian et al., 1981)

Nitrate is reduced to nitrite in humans and animals in their gastrointestinal tract. Vegetables represent a major source of nitrate in human diets. Nitrate in some vegetables (e.g., lettuce and spinach) has been reported to be converted to nitrite during storage (Gersons, 1974).

Nitrite reacts with hemoglobin to form methemoglobin and causes impairment to oxygen transport (Methemoglobinemia). In humans when the methemoglobin concentration exceeds 70%, asphyxia occurs. At lower levels the reaction is reversible. Apparently the reaction of nitrite with hemoglobin is inconsequential in adults, but it can be critical in infants (Committee on Nitrate Accumulation, 1972; Wolff and Wasserman, 1972). In cattle, abortion was associated with a methemoglobin level of 40% (Wolff and Wasserman, 1972).

Nitrosamines are toxic derivatives of nitrate and nitrite as well as of secondary and tertiary amines. Nitrosamines may have carcinogenic, teratogenic (impaired development of embryo foetus) and mutagenic (cause of chromosomal aberation and gene mutation) properties. Nitrosamines occur in foodstuffs such as cooked bacon, polluted air, water, and tobacco plants (Committee on Nitrate Accumulation, 1972). Nitrosamines precursors may be converted to nitrosamines in the stomachs of mammals (Deeb and Sloan, 1975).

Lorenz (1978) has reviewed various works concerning the potential toxic level of nitrate for humans. Sollman (1957) has given 0.70 g of nitrate-N as a possible single lethal dose for humans. This result agrees with that proposed by Brown and Smith (1967), who stated that an adult weighing 70 kg would need to ingest approximately 0.7 to 1.0 g of nitrate-N for a toxic dose. Deeb and Sloan (1975) set the lethal dose at 18 to 68 mg nitrate-N kg^{-1} of body weight for adults. The lethal dose for nitrite was 22 to 33 mg nitrite-N kg^{-1}. The U.S. Public Health Service (1962) suggested limits and ranges of nitrate-N in food and vegetables are as follows: (1) zero for squash and tomatoes for strained baby foods and 833 ppm nitrate for spinach. (2) 50 ppm (0.005%) for asparagus (dry weight) and 3600 ppm (0.36%) for spinach (dry weight).

Toxic levels of nitrate for animals vary greatly and depending upon other factors. Lorenz (1978) has reviewed this subject and it appears that a level of 0.20% nitrate-N on a dry weight basis is potentially dangerous in livestock. The University of Missouri (1958) has suggested that hay with less than 0.08% nitrate-N is safe for cattle while levels above 0.21% may result in death. They suggest that the nitrate-N intake for a cow should not exceed 12 g per day. The minimum lethal dose of nitrate is about 15 g per 45.4 kg of animal weight. Deeb and Sloan (1975) list levels of 75 to 140 mg nitrate-N kg^{-1} of body weight as the toxic level for cattle and slightly lower values for sheep.

Sources of nitrate for animals include a wide range of pasture plants and green feeds (e.g., barley, wheat, corn, sugar beet, sunflower, turnips, pigweed, thistle, lamb's quarter, bindweed, nightshade, ragweed, certain algae, and sometimes alfalfa). Animal processed food, such as soybean meal and molasses from cane and sugar beets also contain nitrate. Nitrate-accumulating plants become the source of nitrite for animals when the plant materials are bruised and acted upon by plant enzymes or bacteria. Moreover, any nitrate-containing food or feed, processed by bacterial fermentation may, at some stage, contain appreciable amounts of nitrite. Thus, silage prepared with water high in nitrate, commonly contains some nitrite, especially in the early stages of fermentation (Committee on Nitrate Accumulation, 1972).

2.5 Factors affecting nitrate accumulation in vegetables

Two opposing processes regulate nitrate accumulation by plants, nitrate uptake and nitrate assimilation. Any factors that exert influence on these processes will, in turn, affect nitrate accumulation. Before nitrate can be assimilated, it must first be reduced to nitrite then to ammonium. The first enzyme which catalyzes this process is nitrate reductase.

2.5.1 Nutrient supply

Available soil nitrogen is the most important factor in nitrate accumulation in plants (Maynard and Barker, 1972). Nitrate in plants is derived primarily from soil organic matter, plant residues, manures and fertilizer nitrogen. The amount, source, time, method of application, and numerous environmental conditions govern the effects of N fertilizers on nitrate accumulation in vegetables (Maynard et al., 1976).

Increasing rates of N application increase the nitrate concentration of vegetables (e.g., spinach [Barker et al., 1971], table beets [Peck et al., 1971], and many other vegetables [Lorenz, 1978]).

Due to mineralization and nitrification, nitrate is the primary N form absorbed by most plants regardless of the type of N applied. Therefore, within limits, as much nitrate may be accumulated from organic or ammoniacal fertilizers as from nitrate fertilizers if sufficient time is allowed for mineralization and nitrification to occur (Peck et al., 1971). Usually, however, nitrate accumulates less from ammoniacal and urea fertilizers than from nitrate sources (Barker et al., 1971; Peck et al., 1971; Lorenz and Weir, 1974).

Nitrate concentration in plants is also affected by the timing of N application. For example, spinach and table beets (Barker et al., 1971; Peck et al., 1971) accumulated more nitrate when they were exposed to the same quantity of nitrate fertilizer earlier and for longer periods (i.e., broadcast application as opposed to side-dressing one week before harvest).

The accompanying cation influences nitrate absorption and, hence, its accumulation by plants. Ammonium ion suppressed nitrate absorption more than Ca, K, Na, or Mg ions (Minotti et al., 1969). There is much evidence to show that increasing K supply increases nitrate accumulation (Barker, 1962; Minotti et al., 1968). Solution culture studies have shown that K generally stimulates nitrate absorption with respect to the effects of other cations (Minotti et al., 1968; Tottingham et al., 1934). Potassium has also been found to be the most regular counterion for transport of nitrate ion from root to shoot (Locher and Brouwer, 1964; 1965; Louwerse and Alberda, 1965; Minotti et al., 1968).

Phosphorus supply does not have a strong effect on nitrate accumulation by vegetables. Cantliffe (1973) did not find any influence of fertilizer P on nitrate concentration in spinach and table beets. Brown and Smith (1967) in their field study on 30 species of vegetables showed that low P levels had little effect on nitrate levels in plants. On the other hand, Baker and Tucker (1971) reported that the addition of P reduced the amount of nitrate-N in wheat.

2.5.2 Genetic factor

Nitrate accumulation is a function of variety in spinach (Barker et al., 1974), and lettuce (Maynard et al., 1976). Savoyed-leaf spinach varieties tend to accumulate more nitrate than smooth-leaf varieties, and semi-savoyed leaf types fall between them (Barker et al., 1974). Differences in nitrate accumulation may be related to differences in uptake, assimilation, or translocation. Olday et al. (1976) observed that nitrate reductase activity in smooth-leaf spinach was higher than in savoyed-leaf types. It appears that differential assimilation is the primary cause for the observed differences in spinach varieties.

The lettuce variety that accumulated least took up N most (Maynard et al., 1976).

Maynard et al. (1976) suggested that the ratio of nitrate-N to total N could be taken as an indirect measure of assimilatory capacity. This ratio varied greatly among varieties.

2.5.3 Environmental factors

Environmental factors which affect nitrate accumulation in plants include: light intensity, photoperiod and light duration, water relation, and temperature.

Cantliffe (1972b and 1972c) observed that increased nitrate reductase activity associated with high light intensity and long light duration decreased nitrate accumulation in spinach and other vegetables. The need for light to activate nitrate reductase results in a diurnal fluctuation in nitrate concentration. More recent work on spinach by Steingrover et al. (1982) on spinach gave similar results. A 'low-light' treatment, where plants were exposed to low light intensity throughout the night as opposed to normal darkness, seemed to affect nitrate reduction rather than nitrate uptake and transport. Nitrate reductase activity in the leaf blades of the 'low light' treated plants was about twice that in the 'dark-treated' plants. It was suggested that a 'low-light' treatment one night before the harvest may provide a way to lower the nitrate content of commercially grown vegetables.

Shading increased nitrate-N content in tall fescue (*Festuca arundinacea* Schreb.), a nitrate accumulating forage crop (Stritzke et al., 1976). Death of cattle grazing on tall fescue was attributed to nitrate poisoning. This study showed that 30% shade and high N fertility increased the nitrate-N content of tall fescue significantly over those that received less shade and lower N.

Moisture stress leads to excessive nitrate accumulation in forage (Wright and Davison, 1964). Water stress affects general assimilatory processes in plants and reduces nitrate reductase activity (Huffaker et al., 1970), so that nitrate assimilation is depressed. A more recent study by Leclerc and Robin (1983) showed that if soil water content of his test sample was near or below 2%, marram grass (Ammophila arenaria L.) diminished its assimilation activity, and stored nitrate. Above 2% soil water content, the nitrate reductase activity increased and the endogenous nitrate was consumed. Several other processes in soils and plants that are moisture-dependent such as microbial activity, movement of N to absorbing roots, and transport in the xylem appear to increase nitrate levels in plants (Wright and Davison, 1964).

Maynard et al. (1976) speculated on the possible effects of humidity and, thus transpiration, on nitrate accumulation. They postulated that reduced humidity and increased transpiration rates were involved in maintaining a continuous movement of nitrate to reduction sites, thereby helping to maintain nitrate reductase and keeping accumulated nitrate low. The authors postulated that high humidity might enhance nitrate accumulation and suggested that the higher nitrate in glasshouse plants relative to plastic-house plants (10% lower light intensity in plastic house) might not be due to the light intensity effect but rather to the higher humidity in glasshouses.

There is considerable evidence to show that high temperatures increase nitrate content in various plants such as barley (Hordeum vulgare L.) (Onwueme et al., 1971), lettuce (Frota and Tucker, 1972), corn (Zea mays L.) (Mattas and Pauli, 1965), pasture plants (Bathurst and Mitchell, 1958), and spinach (Cantliffe, 1972a). Cantliffe (1972a) attributed this effect to deactivation of nitrate reductase and also to higher soil availability of nitrate resulting from increased microbial activity at high temperatures.

According to Maynard et al. (1976) a general statement about the effects of temperature on nitrate accumulation should not be made, because N absorption, translocation and assimilation are all affected by temperature. The relative degree to which each process was affected depended on other factors. Factors such as light, moisture, and N availability are important which could in turn, be markedly affected by temperature. They cited examples of the effects of the interactions of two factors on N accumulation. Cantliffe (1972a) noted that nitrate accumulation in spinach was affected by the interaction of temperature and amount of N applied. At zero fertilizer N, nitrate accumulation did not begin until temperature was greater than $15^{o}C$, but at 50^{o} and 200 mgN kg^{-1} soil, nitrate accumulation began at $10^{o}C$ and $5^{o}C$, respectively. Hoff and Wilcox (1970) reported effects of temperature and light interaction on nitrate accumulation in tomatoes (Lycopersicon esculentum Mill.). They found that temperature exerted its greatest effect (highest nitrate accumulation) at high N and low light and that light exerted its greatest effect at high temperature and high N.

2.6 Relationship between total N and nitrate-N concentrations in plants

Terman et al. (1976) have shown that total N and nitrate-N concentrations in plants are related. In pot and nutrient solution experiments, nitrate-N accumulation by corn commenced when total N exceeded 2.5% in the leaves and 1.5% in the stems. In spinach and mustard, nitrate-N concentration increased rapidly when total N exceeded 4.0% but approached zero below 4.0%. Nitrate-N in fescue grass was less than 0.1% up to 3% of total N and beyond that increased linearly with total N. The workers concluded from these studies that:

1. The occurrence of high levels of total and nitrate-N during early growth depended on the abundance of available soil and fertilizer N.

2. As plant growth continued, total and nitrate-N decreased as a result of dilution and assimilation. Such decreases occurred with age and in response to P, K, and other factors.

3. As total N decreased all forms of unassimilated N were depleted.

4. Except during the early growth stage, high nitrate-N concentrations in plants are usually the result of diminished growth due to unfavorable conditions such as drought, low or high air temperatures, poor light, together with continued uptake of nitrate-N.

5. If the rate of plant growth was higher than that of N absorption, much of the nitrate would be incorporated into proteins. However, low concentrations of nitrate-N ($< 0.05\%$) can remain in conductive tissues.

2.7 Chemistry of oxalate with an emphasis on its biosynthesis in plants

Franceschi and Horner (1980) have reviewed studies on the synthesis of oxalic acid in high oxalate plants such as rhubarb, buckwheat, *Begonia*, *Oxalis*, *Atriplex*, *Setaria*, spinach, and beetroot. According to Raven et al. (1982), there are four major pathways of oxalate biosynthesis. Interestingly, all four pathways have been suggested for spinach. The four pathways are shown in Figure 2.1 and include:

1. Formation of glyoxylate from glycollate, by the action of glycollate oxidase, followed by oxidation of the glyoxylate to oxalate by action of the same enzyme.

2. Formation of glyoxylate from isocitrate by the action of isocitrate lyase, followed by oxidation of glyoxylate to oxalate.

3. Formation of oxalate from oxaloacetate by the action of oxaloacetate lyase.

4. Formation of oxalate from C_1 and C_2 of L-ascorbate.

The first 2 mechanisms have glyoxylate as the immediate precursor of oxalate. Glyoxylate is oxidized to produced oxalate (reaction):

$$\underset{\text{glyoxylate}}{\begin{array}{l} CHO \\ | \\ COOH \end{array}} \longrightarrow \underset{\text{oxalate}}{\begin{array}{l} COOH \\ | \\ COOH \end{array}} \qquad (1)$$

Mechanism 1 appears to have some connection with photosynthesis, or more precisely, photorespiration. The conversion of glyoxylate to oxalate occurs in green tissue and is facilitated by light (Sengupta and Sen, 1976). Both photorespiration and oxalate synthesis via mechanism 1 use the same substrate, glycollate, with subsequent formation of glyoxylate.

Mechanism 2 is contrastingly different from mechanism 1 because oxalate is synthesized in the dark. β-carboxylation of phosphoenol pyruvate (PEP) provides the basis of a non-crassulacean acid metabolism common in plant tissue. This process is also called dark CO_2 fixation

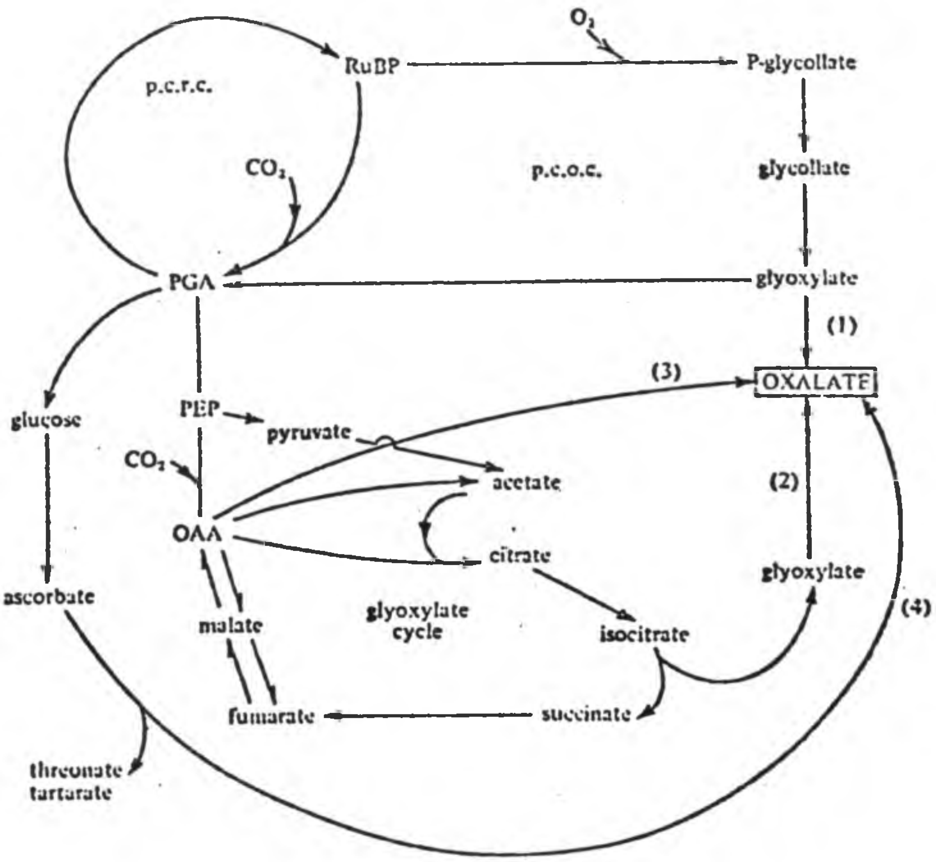


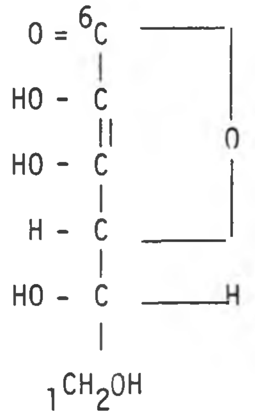
Figure 2.1 The four proposed pathways to oxalate: (1) from phosphoglycolate generated in the RuBPo reaction; (2) from glyoxylate produced in the isocitrate lyase reaction; (3) from oxaloacetate via oxaloacetate lyase; (4) from ascorbate by oxidation.
OAA = Oxaloacetic acid; p.c.o.c. = photosynthetic carbon oxidation cycle; p.c.r.c. = photosynthetic carbon reduction cycle; PEP = phosphoenol pyruvate; PGA = 3-phosphoglycerate; P-glycollate = phosphoglycollate

(Source: Raven et al., 1982).

because it does not require light. The products of this CO_2 fixation are C_4 compounds which can enter the tricarboxylic acid (TCA) cycle to be metabolized with subsequent energy generation. According to Osmond and Avadhani (1968) oxalate is not an early product of carboxylation reactions but is synthesized from intermediates of subsequent TCA cycle metabolism. The TCA cycle intermediate that is a likely oxalate precursor is isocitrate, which gives rise to glyoxylate by the action of isocitrate lyase.

Mechanisms 3 and 4 do not have glyoxylate as the substrate for oxalate. Chang and Beevers (1968), who discovered mechanism 3, indicated that oxalate was produced as a by-product of acetate utilization in the TCA cycle. Oxalate synthesis involves the cleavage of C_4 oxaloacetate to yield acetate and oxalate. The enzyme which catalyzes this reaction is oxaloacetate lyase.

Mechanism 4 uses L-ascorbic acid as a precursor of oxalic acid. This mechanism has been found in many oxalate accumulating plants, such as *Rumex crispus* L. (curly dock), *Amaranthus retroflexus* L. (red root pigweed), *Chenopodium album* L. (Lamb's quarters), *Beta vulgaris* L. (sugar beet), *Halogeton glomeratus* M. Bieb. (halogeton), and *Rheum rhabarbarum* L. (rhubarb) (Nuss and Loewus, 1978), and also in species with low oxalate content, such as barley (Wagner, 1981). It was found by labelling studies that C_1 and C_2 fragments of ascorbic acid give rise to the carbons in oxalic acid (refer to the structure of the acid below) (Nuss and Loewus, 1978). More biochemical work needs to be done to establish the enzymic basis of this conversion and to determine the site of the activity.



L-ascorbic acid

Recent work on the subject of oxalate biosynthesis by Raven et al. (1982) uses non-radioactive isotopes, $^{18}O_2$, ^{12}C, and ^{13}C, to investigate the relative significance of the four mechanisms of oxalate biosynthesis. Their results indicate that the role of mechanism 1 is not important for oxalate synthesis in spinach. This mechanism is the only one that requires light or in other words, is the only one that occurs in green tissue. Earlier work has shown that organic acid or carboxylate synthesis is connected to dark CO_2 fixation (e.g., Osmond and Avadhani, 1968; Chang and Beevers, 1968).

2.8 Relation between oxalate synthesis, nitrate accumulation and nitrogen metabolism in plants

There are connections between oxalate synthesis, nitrate accumulation, and nitrogen metabolism in plants. As mentioned in section 2.5, nitrate accumulation depends upon the rate of nitrate uptake and the rate of nitrate assimilation. Nitrates accumulate in plant tissue when the rate of nitrate assimilation ceases or is slow. Nitrate enters the protein metabolism pathway after it is reduced to ammonia. The connection between protein metabolism and carboxylate (organic acid) synthesis will be described.

Studies on nitrate and oxalate accumulations on different spinach varieties have shown that there is a relationship between leaf type and nitrate and oxalate accumulations. Savoyed-leaf spinach cultivars tend to accumulate the most nitrate while smooth-leaf spinach are able to maintain low nitrate concentrations. The semi-savoyed leaf type behave in an intermediate manner (Barker et al., 1974; Maynard and Barker, 1974). On the other hand, Kitchen et al. (1964a) found the savoyed-leaf types to have the lowest oxalate content and smooth and semi-savoyed leaf types to have the highest content. While this can be taken as evidence of the connections between nitrate accumulation, N metabolism and oxalate accumulation, it is not a direct one.

Studies on the role of carboxylic acids in nitrogen metabolism up to the mid 1960s were reviewed by Beevers et al. (1966). The effects of ammonium and nitrate ions on organic acid contents have been observed in various plants (Beevers et al., 1966, p. 231). The acid content increases in plants treated with ammonium or nitrate nitrogen relative to the untreated ones, and the increase is greater in nitrate-fed plants than ammonium-fed plants (Beevers et al., 1966; Kirkby and Mengel, 1967; Kirkby, 1969; Kirkby and Knight, 1977; Vityakon, 1979). Similar response to ammonium and nitrate has been found in oxalate accumulating plants such as spinach and beetroot (Vityakon, 1979).

According to Beevers et al. (1966), ammonium and nitrate utilization impinged directly upon the metabolism of carboxylic acids. Work in the 1970s and 1980s has used isotopically labelled CO_2 to examine the effects of ammonium and nitrate nutrition on dark CO_2 fixation. Ikeda and Yamada (1981) investigated the effect of ammonium and nitrate nitrogen on dark CO_2 fixation in tomato leaves. Dark CO_2 fixation involves the enzyme phosphoenol pyruvate carboxylase which catalyses the following reaction:

$$\underset{\text{phosphoenol pyruvate}}{\text{PEP}} + CO_2 \longrightarrow \underset{\text{oxaloacetate}}{\text{OAA}} + \underset{\text{inorganic P}}{P_i} \qquad (2)$$

Ammonium-fed plants were remarkably less able to fix $^{14}CO_2$ in the dark compared with nitrate-fed plants. Furthermore, the phosphoenol pyruvate carboxylase activity of ammonium-fed plants was lower than that of nitrate-fed plants. Fixed $^{14}CO_2$ was more rapidly utilized for amino acid synthesis in ammonium-fed plants than in nitrate-fed plants.

More than 50% of total organic acids in tomato consist of malic acid. Not only is malic acid synthesized through the TCA cycle in mitochondria but it is also produced by the carboxylation of C_3 compounds catalyzed by soluble enzymes in the cytoplasm (i.e., oxaloacetate produced in reaction 2 can be metabolized to malate by the enzyme malate dehydrogenase). Inference can also be made concerning the synthesis of oxalate from the oxaloacetate precursor produced in reaction 2 along the pathway of mechanism 2 or 3.

Hammel et al. (1979) investigated the effect of ammonium on carbon metabolism in isolated mesophyll cells of Papaver somniferum L. Ammonium chloride solution was used as the nitrogen source. Addition of ammonium ion to isolated mesophyll cells resulted in an increase in the rate of dark ^{14}C fixation relative to that in untreated cells. The most rapid increase in labelling the metabolite occurred in aspartate and was accompanied by a decrease in the level of labelled phosphoenol pyruvate. This indicates that ammonium stimulates phosphoenol pyruvate carboxylation in this system.

Possible effects of ammonium on glycolysis and respiratory metabolism were investigated by Hammel et al. (1979). The level of labelled pyruvate did not change nor were there effects of ammonium on the pyruvate kinase reaction in the dark (reaction 3). Such results indicate that ammonium is not important to the reaction:

$$\text{PEP} \xrightarrow{\text{pyruvate kinase}} \text{enol pyruvate} \longrightarrow \text{pyruvate} \quad (3)$$

However, Ikeda et al. (1974) showed that there was an enhancement of glucose degradation (glycolysis) and respiratory metabolism (TCA cycle) in the leaves of tomato plants supplied with high levels of ammonium nitrogen for seven consecutive days. They suggested that the enhanced respiration in ammonium-fed plants is due to assimilation/detoxification of NH_4^+-N. This reaction keeps the levels of NH_4^+ - N and organic acids low. The organic acids are replenished mainly by intermediates in glycolysis and the TCA cycle.

Paul et al. (1978) reported the enhancement of both pyruvate kinase and phosphoenol pyruvate carboxylase in isolated mesophyll cells of Papaver somniferum L. supplied with ammonium and light. They concluded that the net effect of an addition of ammonia to mesophyll cells was a redistribution of newly fixed carbon away from carbohydrates and into amino acids.

In a study of effect of ammonium on dark CO_2 fixation products of Euglena, Peak and Peak (1980) measured an overall increase in glutamine and the amount of $^{14}CO_2$ fixed. Both were heavily labelled. Furthermore, they postulated with some supporting evidence that the labelled CO_2 entered the amino acids via the TCA cycle by way of the carboxylation of phosphoenol pyruvate.

Peak and Peak (1980) reported that ammonium stimulation caused increased incorporation of labelled CO_2 into some amino acids not derived from TCA cycle intermediates including for example, glycine, serine, and alanine, which are all derived from the glycolytic pathway. Since it is known that Euglena possesses the glyoxylate shunt enzymes isocitrate lyase and malate synthase, these researchers suggested that it should be feasible that CO_2 could enter glycine and serine via the TCA cycle intermediates, oxaloacetate and isocitrate, which are glyoxylate precursors.

Although the studies presented so far do not directly relate nitrogen to oxalate synthesis, the connections of these nitrogen-related biochemical processes to oxalate metabolism can be seen. The process of dark CO_2 fixation, which involves the enzyme phosphoenol pyruvate carboxylase and the product oxaloacetate is a direct precursor of oxalate formation; also oxaloacetate can lead to the synthesis of isocitrate, which can lead to the synthesis of glyoxylate by the catalysis of isocitrate lyase. Furthermore, these studies have thrown some light on the long-observed phenomenon of a relatively higher organic acid content (including oxalate) in nitrate-fed plants compared with ammonium-fed plants.

2.9 The use of amaranth, cassava, and taro as vegetables

Amaranth, cassava, and taro have been consumed in the tropics since ancient times. Amaranth was an important grain crop of the Aztecs and the Incas (National Research Council, 1984). Taro is grown throughout the humid tropics for edible corms and leaves as well as for traditional ceremonial uses (Wang, 1983). Although widely used, the term 'under-exploited' crop has been applied to amaranth and taro (National Academy of Science, 1975) because they are relatively unknown to the industrialized world. In contrast, in the industrialized world key food crops have been bred to suit large scale monoculture farming systems with consequent high yields for economic purposes. From this point of view, cassava is different from amaranth and taro. Cassava is a 'well-known' root crop, now grown on a large scale and is an important commodity in international trade. Much research work has been done on cassava, for example at the Centro Internacional de Agricultura Tropical (CIAT) in Columbia. The use of cassava leaves is relatively unknown although they are rich in protein.

2.9.1 Distributions of the crops and their uses

Amaranth seeds and leaves are used for human consumption. Principal uses and areas of origin of many *Amaranthus* species are summarized in Table 2.3. Amaranth grows in many regions of the world. As far as the edible vegetative parts (i.e., leaves and young shoots) are concerned, *Amaranthus* species such as *A. tricolor*, *A. dubius*, and *A. cruentus*, are grown for their value as soup vegetables or for boiled salad greens particularly in the hot, humid regions of Africa, Southeast Asia (especially Malaysia and Indonesia), southern China, southern

Table 2.3

Uses and areas of origin of *Amaranthus* species
(after Teutonico and Knorr, 1985)

Species	How found	Use	Area of origin
A. blitum (*A. lividus*, *A. oleraceus*)	Cultivated	Vegetable, ornamental	Asia
A. caudatus *A. edulis* (*A. mategazzianus*)	Cultivated	Grain, vegetable, ornamental	South America (Andes)
A. cruentus (*A. paniculatus*)	Cultivated	Grain, vegetable	South America (Guatemala)
A. dubius	Weed, cultivated	Vegetable	South America
A. hybridus	Weed	Vegetable	South America
A. hypochondriacus (*A. leucocarpus*, *A. leucosperma*, *A. flavus*)	Cultivated	Grain, vegetable	North America (Mexico)
A. retroflexus	Weed	Vegetable	North America
A. spinosus	Weed	Vegetable	Asia
A. tricolor (*A. gangeticus*, *A. mangostanus*)	Cultivated	Vegetable	Asia
A. viridis (*A. ascendens*, *A. gracilis*)	Weed	Vegetable	Africa

India, and the Caribbean. A. palmeri is a major wild green for the Indians in the North American deserts, and A. blitum leaves have been a favorite salad in Greece since ancient times (National Research Council, 1984). Amaranthus species along with other wild plants are used by the Tanzanians as relishes that are an integral and essential part of the diet in all seasons of the year (Fleuret, 1979).

Taro (Colocasia esculenta (L.) Schott.) is a member of the Araceae family. Primarily it is a root crop but leaves are also consumed extensively in Africa, Asia, the West Indies, and South America. However, taro consumption is greatest in the Caribbean, Hawaii, the Solomon Islands, American Samoa, Western Samoa, the Philippines, Fiji, Sri Lanka, India, Nigeria, Indonesia, New Hebrides, Tonga, Niue, Papua New Guinea, and Egypt. Young taro leaves are an important vegetable throughout Melanesia and Polynesia (Wang, 1983).

Cassava (Manihot esculenta L.) is one of the most important root crops of the world. The root is the fourth most important energy staple of the tropics, providing food and income for 750 million people in three continents of Africa, Asia and America.

The consumption of cassava leaves as a vegetable is widespread among the native peoples of many Asian countries such as Malaysia, Indonesia, and Thailand. The cyanide content of cassava leaves precludes their use as a vegetable in Nigeria (Oke, 1968).

2.9.2 Nutritional values and some limitations

Considerable work has been done in India on evaluating the nutritional value of amaranth. Many species of amaranth are used as greens in India and their nutritional value to low income groups is well known.

According to Rao et al. (1980), amaranth is considered the king of vegetables with regard to its nutritional value and its low price. Like many other green leafy vegetables in India, amaranth is 'within reach of the poor man'. Much of the research has been focused on the use of amaranth as a food supplement. For example, Devadas et al. (1964) investigated the use of amaranth and other green leafy vegetables as supplements for rice-based diets. They found that amaranth and vegetable supplements improved the calcium status of the body as indicated by a positive calcium balance and higher calcium levels in the bones of experimental albino rats. In addition, the overall growth of animals on a diet that included amaranth was improved.

Amaranth, like other green leafy vegetables, is an important source of vitamins A and C, which are of considerable nutritional significance (Table 2.4) (National Research Council, 1984; Teutonico and Knorr, 1985). In places like Kenya amaranth also provides a cheap source of vitamin C relative to more expensive sources like citrus (Abe and Imbamba, 1977).

With regard to minerals, amaranth has high iron and calcium contents relative to other greens such as spinach, Malabar spinach (Basella) and chard (National Research Council, 1984). Guttikar et al. (1966) also reported that amaranth greens (*A. tricolor*) was a very rich source of magnesium when compared with other Indian foodstuffs including pulses, leafy vegetables, other vegetables and fruits. Data reported by Teutonico and Knorr (1985) confirm that amaranth contains potassium, iron, magnesium and calcium in significant concentrations (Table 2.4).

Protein is another important nutrient of amaranth greens. Its leaf can be used in the wet tropics to ameliorate protein shortages (Pirie,

Table 2.4

Composition of vegetable amaranth

Analysis	Content									
	A. cruentus	A. edulis	A. hypochondriacus	A. retroflexus	A. tricolor	A. caudatus	A. spinosus	A. viridis	A. graecizans	A. hybridus
Moisture	-	-	-	-	85.7	70.1-90.9	79.0-83.0	94.0	84.0	-
Crude protein (%N x 6.25 dm)	20.9-33.0	18.0	21.6	21.1-21.2	32.7	17.4-29.7	28.4-31.0	38.3	23.2	22.1-33.5
Total lipids[a]	1.58-6.7	1.60	1.96	1.58	3.5-10.6	1.0-2.8	1.8-4.5	1.7	1.7-3.2	1.3-6.5
Crude fiber[a]	8.6-13.1	12.4	11.8	13.1-13.5	7.0	5.4-9.2	9.4	13.3	14.5	10.5-24.6
Crude ash[a]	16.1-21.6	22.0	21.2	20.4-22.2	-	19.3-21.0	22.1	-	21.7	7.6-19.0
Na[a]	-	-	-	-	-	0.01-0.04	0.01	-	0.01	-
K[a]	2.9-6.1	3.7	5.6	5.4-5.6	-	0.3-5.0	0.3	-	0.2	-
Ca[a]	1.9-2.6	6.2	2.6	3.0	3.5	2.3-2.6	1.1-1.8	2.3	1.8	3.3
Mg[a]	1.1-2.2	2.2	1.2	1.4-1.7	1.7	1.1-1.3	2.2	-	1.5	-
Fe[a]	0.02-0.04	0.02	0.02	0.04-0.05	-	0.02	0.01	0.008	-	0.00
Zn[a]	0.05	0.002	0.004	0.005-0.008	-	-	-	-	-	-
P[b]	0.4	0.3	0.5	0.3-0.5	0.7	0.3-0.4	0.4	-	-	-
Riboflavin[b]	-	-	-	-	2.1	-	-	-	-	-
Niacin	-	-	-	-	8.4(0.8[c])	4.7	7.7	-	6.2	-
Ascorbic acid[c]	-	-	-	-	693(55[c])	210	250	147	-	30-48[c]
Thiamin[c]	-	-	-	-	0.02	-	-	-	-	-
-carotene (IU/100 g dm)	-	-	-	-	23,000 (1,710[d])	25,400	54,110	48,000	-	-

a % dry matter b mg/ 100 g dry matter c mg/ 100 g fresh weight d g/ 100 fresh weight

Source: Teutonico and Knorr, 1985.

1966). Leaves of this and other specific tropical plants contain protein of high quality (Akeson and Stahmann, 1965; Gerloff et al., 1965 as cited by Madamba, 1972). Attempts to promote the use of leaf protein have been underway for some time in the tropics. In Nigeria the traditional corn grinding mill was used to extract leaf protein from vegetables such as Amaranthus caudatus (Olatunbosun, 1976). Adding approximately 10 g of leaf protein a day to the low protein diet of children suffering from protein-calorie malnutrition resulted in significant clinical improvement.

Research on the production of protein concentrate from amaranth leaves (e.g., Carlsson, 1980 in Sweden, Cheeke et al., 1981) has been designed to make proteins in green plants available to non-ruminants because leaf protein concentrate no longer has the cellulose and fiber that is indigestable to non-ruminants. Amaranthus species contain large amounts of extractable protein (Lexander et al., 1970), but protein concentrates from amaranth have not improved growth of experimental rats. Cheeke et al. (1981) postulated that poor growth may be associated with a high ash content and organic substances such as saponins, phenolics, and oxalates. These factors need to be overcome before amaranth or its protein concentrate can be utilized successfully.

The lysine content of amaranth is high. This amino acid is frequently deficient in cereal-based diets (Oliveira and de Carvalko, 1975; Kamath and Sahonie, 1959). Oliveira and de Carvalko (1975) reported that in Mozambique, A. spinosus leaves had lysine contents as high as 5.2%. The benefit of supplementing a maize meal with A. spinosus was evidenced by the fact that the chemical score of the mixture was raised to 43, compared to 28 for maize meal alone and 32 for amaranth leaves alone.

The National Research Council (1984) has reported leaf-protein levels (on a dry weight basis) as follows: 27% for A. blitum, 28% for A. hybridus, 30% for A. caudatus, 32% for A. gracilis, 23% for A. graecians and 28% for A. spinosus. The range of protein content in various species of amaranth is presented in Table 2.4.

Taro leaves

Young leaves and petioles of taro are used as vegetables. They are useful sources of vitamin A and vitamin C (Table 2.5). Taro leaves are used extensively for cooking in Pacific islands such as Hawaii, Fiji, Samoa and Tonga. Taro leaves are also rich in mineral calcium and potassium (Table 2.5) (Standal, 1983). Crude protein contents are comparable to those of amaranth and cassava as shown in Table 2.5.

Cassava leaves

Cassava leaves are rich in protein, carotenes, vitamins B_1, B_2, and C, and minerals (Oke, 1968). Rogers and Milner (1963) reported that the protein content of cassava leaves ranged from 17.8 to 34.8% on a dry weight basis for Brazlilian varieties and from 18.5 to 32.4% for Jamaican varieties. Concentrations of essential amino acids are adequate except for methionine (Eggum, 1970; Rogers and Milner, 1963). Adding methionine to a diet of cassava leaves raised the biological value from 49 for the leaves alone to 80 for the mixture (Eggum, 1970). Rogers and Milner (1963) considered the composition of essential amino acid of cassava leaf protein to be similar to that of soybean, which is one of the best in nutritive value among the readily available

Table 2.5

Nutrient composition of taro leaves

Composition per 100 g of fresh wt.	India	Philippines	Hawaii
Edible portion (%)	-	55.0	-
Moisture (g)	78.8	79.6	88.0
Protein (g $100g^{-1}$ dry wt.)	32.1	21.6	22.7
Fat (g)	2.0	1.8	0.7
Carbohydrates (g)	8.1	12.1	4.8
Fiber (g)	1.8	3.4	2.0
Food energy (kcal)	77.0	69.0	36.0
Ash (g)	-	2.0	2.0
Calcium (mg)	460.0	268.0	107.0
Phosphorus (mg)	125.0	78.0	60.0
Iron (mg)	38.7	4.3	2.3
Sodium (mg)	-	11.0	2.0
Potassium (mg)	-	1237.0	437.0
Vit. A value (IU)*	2000	20385.0	5028.0
Thiamine (mg)	0.1	0.1	0.14
Riboflavin (mg)	0.5	0.33	0.31
Niacin (mg)	1.9	2.0	1.0
Ascorbic acid (mg)	63.0	142.0	37.0

* 0.6 ug = 1 IU

Source: Standal, 1983

vegetable proteins. The use of cassava leaf for producing protein concentrates is being investigated by several food scientists (e.g., Luiza et al., 1979).

The vitamin A content of cassava leaves is as high as 0.5 unit g^{-1}. Various sources report vitamin C content ranging from 29 to 180 cmol kg^{-1} in cassava leaves (Oke, 1968).

Limitations

Amaranth, taro, and cassava leaves contain oxalate and accumulate a certain amount of nitrate. The presence of an antinutrient and toxic agent lowers the nutritive value of these vegetables, as discussed in section 2.2.

2.10 Estimation of oxalate contents

Two techniques of oxalate quantification are to be discussed. The first, termed the 'classical method', was developed through a series of improvements of existing techniques before the 1950s. Papers by Baker (1952) and Moir (1953) are frequently cited by researchers who use the 'classical method' in their work. The Association of Official Analytical Chemists (AOAC) has certified this technique for total oxalate determination (Horwitz, 1975).

The classical method of oxalate determination has three steps:

1. Separation of oxalate by means of calcium oxalate precipitation at pH 4-5;

2. Determination of calcium by titrimetric or spectrophotometric methods;

3. Calculation of oxalate equivalents from calcium analysis (Baker, 1952; Moir, 1953; Horwitz, 1975).

One difference between the methods employed by Baker (1952) and Moir (1953) is that Baker used fresh plant material to avoid loss of oxalate from drying whereas Moir used dried ($100^{o}C$), plant material.

Baker (1952) proved the effectiveness of this technique by demonstrating 99-100% recovery of added oxalate.

The second technique is based on the use of high performance liquid chromatography (HPLC) developed in the 1970s. In HPLC a mobile phase is allowed to percolate through the stationary phase packed in a column continuously and the sample in the same solvent as the mobile phase can be injected into the mobile phase as desired.

A paper describing the effectiveness of the HPLC technique for determining oxalic acid and comparing this technique with the classical method has been published (Libert, 1981). Libert used a reversed-phase column called the Lichrosorb RP-8 (C_8) as the stationary phase and a solution containing 0.5% KH_2PO_4 and 0.05 $\underline{M}$ tetrabutyl ammonium hydrogen sulphate (TBA), buffered at pH 2 with orthophosphoric acid, as the mobile phase. One advantage of HPLC is the simultaneous determination of organic acids other than oxalic acid. The determination of oxalic acid levels in rhubarb by the HPLC technique has been shown to give comparable results to the classical method.

CHAPTER III

MATERIALS AND METHODS

In order to test the hypothesis that the variance in the nutritional quality of food crops is strongly influenced by cultural and environmental factors, the following experimental sites, crops, experimental design and data collection and analysis procedures were selected.

3.1 The experimental sites

Four experimental sites were selected to represent a range of agroenvironments. These sites were developed by the Benchmark Soils Project (BSP) of the University of Hawaii to test the hypothesis that agroproduction technology can be successfully transferred from one location to other distant sites around the world provided the biophysical environment of the site where the technology was developed was similar to the transfer site. The project defined similar environments according to the criteria set forth to define the soil family in Soil Taxonomy (Soil Survey Staff, 1975). Soil Taxonomy is a comprehensive system of soil classification for making and interpreting soil surveys issued by the Soil Conservation Service of the U.S. Department of Agriculture.

By 1980, the project had established experimental sites in the Cameroons in Africa, Brazil, Puerto Rico, the Philippines, Indonesia and Hawaii. Three soil families were selected to test the hypothesis that similar agroproduction technologies and management practice would result in similar crop performances and yields among soils belonging to the same soil family regardless of where they occurred. The three soil families selected were the clayey, kaolinitic, isohyperthermic family of the Tropeptic Eutrustox; the thixotropic, isothermic family of Hydric Dystrandepts and the clayey, kaolinitic, isohyperthermic family of Typic Paleudults.

The Tropeptic Eutrustox are found in the warm, semi-arid tropics and are nutrient-rich Oxisols. Experimental sites with this soil were established in Puerto Rico, Brazil and Hawaii. In Hawaii the experimental sites were established in Waipio on the Island of Oahu and on the west end of the Island of Molokai.

The Hydric Dystrandepts are impoverished soils that have formed from volcanic ash and are well known for their low phosphorus levels. The isothermic members of Hydric Dystrandepts occur in the cool tropics and the mean annual temperature is between 15 and 22^{o}C. Experimental sites with soils of this family were established in the Philippines, Indonesia and Hawaii. In Hawaii, the sites were established on the Big Island of Hawaii at Iole and Niulii on the upper slopes of the Kohala Mountains and at Kukaiau on the slope of Mauna Kea.

Experimental sites for the Typic Paleudults were established in Cameroon, Indonesia and the Philippines. These soils are highly acid, nutrient-poor and occur in the warm, humid tropics. No experimental site of this soil was established in Hawaii.

Each experimental site was carefully characterized for soil and provided with a weather station that recorded wind speed and direction, relative humidity, solar radiation, maximum and minimum air temperature, topsoil and subsoil temperatures and rainfall. The results of this project are summarized in a book entitled "Soil-Based Agrotechnology Transfer" (Silva, 1985).

In 1982 a workshop on "A Multidisciplinary Approach to Agro-technology Transfer" (1984) was held at the University of Hawaii. At this workshop, the nutritionists reminded the agronomists that the objective of agriculture research was not simply to increase yield but to provide adequate nutrients for people.

In a paper on the "Relationship of Soil Composition to the Nutrient and Antinutrient Contents of Plants" presented at that workshop, Van Reen (1984) suggested that the data in food composition tables were not very reliable because there is evidence that the composition of the same edible plant grown in different parts of the world is very different (Food and Agriculture Organization, 1954).

In the same paper Van Reen listed factors that may contribute to variations in food compositions. These are:

1. Genetics of the variety of the plant
2. Light intensity and duration (season)
3. Temperature condition
4. Water conditions
5. Soil types
6. Type and amount of pesticide/herbicide
7. Type and amount of fertilizers
8. Age of plant material
9. Part of the sample analyzed.

It was evident from Van Reen's paper that the Benchmark research sites established by the Benchmark Soils Project were ideally suited to assess a number of the factors which could influence variation in nutrient contents.

It was decided to select four Benchmark research sites to test the hypothesis that nutrient composition in general, and antinutrient content in particular, vary with genotype, and environment. These sites were the Waipio site on the Island of Oahu, the Molokai site on the west end of the Island of Molokai, the Iole site in the Kohala district of the Island of Hawaii and the Kukaiau site in the Hamakua District also on the Island of Hawaii. Tables 3.1, 3.2 and 3.3 summarize the characteristics of each site.

3.2 Crops

Three crops were selected on the basis of their availability for growing and/or obtaining samples and their relevance to the nutritional quality of interest, namely the contents of oxalates and some mineral nutrients. These crops were amaranth (*Amaranthus gangeticus* L.), cassava (*Manihot esculenta* L.) and taro (*Colocasia esculenta* (L.) Schott.). These crops, with the exception of amaranth, were part of the existing cropping systems experiments of the Benchmark Soils Project. They were known to have high oxalate contents.

Amaranth belongs to the family Amaranthaceae. It is commercially known in the United States as tampala. In Hawaii, it is also known as Hinn Choi or Chinese spinach. It is a spinach-like vegetable with dark green leaves which are elongated and smooth (Cole, 1979). The plants are succulent, low growing and compact with growth habit much like spinach (National Research Council, 1984). Under optimum conditions, the plants reach their harvestable size in 45 days after seed sowing. The leaves and young tender stem are eaten as greens. *A. gangeticus* L. has been proved to be the same species as *A. tricolor* L.

Table 3.1

Description of geographical positions[a] and history of soil use[b] of the experimental sites

Sites	Geographical position and history of soil use
Kukaiau	This site is situated on the Island of Hawaii, approximately 2.5 km southeast of the town of Honokaa and approximately 0.6 km from a plantation road southeast of the junction of highways 19 and 24 and 0.3 km southeast of an abandoned church. The elevation is approximately 395 m and the slope is moderate to strong (6 percent slope, north aspect). The soil was formerly grown to sugarcane. In 1976, it was planted to soybean and in 1977 to corn. It was then fallowed until 1982 when cropping systems experiments were begun in which the fertilizers (lime, epsom salt, borax and zinc sulfate), in quantities as shown in Table 3.4 were applied yearly. The soil on this site is a member of the thixotropic, isothermic family of Hydric Dystrandepts.
Iole	This site is situated in North Kohala, Island of Hawaii, approximately 5.6 km south southeast of the town of Hawi, approximately 7.2 km southwest of Kapaau village. The elevation is approximately 545 m and the site occurs on moderately sloping to strongly sloping (6 percent slope, north aspect) land. The soil was formerly planted to sugarcane. Maize experiments in which different rates of N and P were applied, were conducted in 1977. It was left fallow after the maize experiments until 1982 when cropping systems experiments were started, and fertilizers (lime, epsom salt, borax and zinc sulfate) in rates shown in Table 3.4 were applied yearly. The soil on this site is a member of the thixotropic, isothermic family of Hydric Dystrandepts.

[a]Source: Ikawa, 1979

[b]Patrick Ching, personal communication

Table 3.1 (continued) Description of geographical positions and history of soil use of the experimental sites

Sites	Geographical position and history of soil use
Waipio	This site is situated on the Island of Oahu, Hawaii, approximately 8 km north of Waipahu and approximately 225 m east of the road leading to Mililani Cemetery from Kamehameha Highway. The elevation was 150 m. It is on nearly level upland (2 percent slope). The land was an abandoned pineapple field and was used to conduct maize transfer experiments in 1978, after which it was left fallow until 1982 when cropping systems experiments were started and the fertilizers (lime, epsom salt, borax and zinc sulfate) of rates shown in Table 3.4 were applied yearly. The soil on this site is a member of the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox.
Molokai	This site is situated in Maunaloa, Island of Molokai, Hawaii, approximately 1.5 km north-northwest of the Maunaloa Village, and approximately 900 m northwest of highway 46. It is at approximately 257 m elevation on gently sloping upland (5 percent). The soil was formerly grown to sugarcane. Maize transfer experiments were conducted in 1980 after which it was left fallow until 1982 when the cropping systems experiments were started and the fertilizers (lime, epsom salt, borax and zinc sulfate) in rates shown in Table 3.4 were applied yearly. The soil on this site is a member of the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox.

Table 3.2

Soil family properties as they relate to the taxa in Soil Taxonomy

Taxonomic name	Inherent soil family characteristics
Thixotropic, isothermic Hydric Dystrandepts	
thixotropic	High surface activity of colloids.
isothermic	Cool soil temperatures (mean annual temperature 15-22^{o}C).
Hydric	Moist, humid soils.
Dystr-	Low base saturation (< 35%).
-andept	Low bulk density (< 0.85 g cc^{-1}), amorphous colloids.
Clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox	
clayey	More than 35% clay in the subsoil.
kaolinitic	Dominated by low activity clay.
isohyperthermic	Warm soil temperatures throughout the year (mean > 22^{o}C); small difference between summer and winter temperatures (< 5^{o}C).
Tropeptic	Moderate structure or less than 125 cm deep; or both.
Eutr-	Moderately enriched with nutrients; medium to high base saturation (>50%).
-ust-	Pronounced dry season (dry for more than 90 cumulative days per year).
-ox	Presence of oxides of iron and aluminum; low cation-exchange capacity.

Source: Benchmark Soils Project, 1979.

Table 3.3

Some physical and chemical properties of the soils at four experimental sites: (a) Kukaiau, (b) Iole, (c) Molokai and (d) Waipio

(a)

Soil name: Kukaiau Classification: Hydric Dystrandepts, thixotropic, isothermic
Soil no.: 75HA-1-1 Location: Honokaa, Island of Hawaii, Hawaii

Depth	Horizon	Particle size analysis: Sand 2-.05	Silt .05-.002	Clay <.002	Bulk density	Water content: .1-bar	.3-bar	15-bar	Organic C	Total N	C/N	Extractable iron: Fe	Fe_2O_3
--cm---		pct < 2 mm			g/cc	pct			pct			pct	
0-17	Ap1								7.34	0.80	9	10.93	15.63
17-23	Ap2								6.53	0.66	10	10.84	15.50
23-42	B21								5.68	0.56	10	10.86	15.53
42-60	B22								5.16	0.47	11	9.64	13.78
60-100	B23								4.63	0.42	11	9.51	13.60
100-130	B24								3.57	0.35	10	14.08	20.13
130-160	B25								5.97	0.53	11	10.90	15.58

Depth	Extractable bases: Ca	Mg	Na	K	Sum	Extractable acid	Cation-exchange capacity: NH_4OAc	Sum	Extractable Al	Base saturation: NH_4OAc	Sum	pH: H_2O	KCl	Difference
--cm---	meq/100 g soil									pct				
0-17	2.53	0.03	0.12	0.51	3.19	56.22	58.69	59.41	< 0.01	5	5	6.00	5.35	-0.65
17-23	1.92	0.01	0.06	0.05	2.04	55.26	67.78	57.30	< 0.01	3	4	6.10	5.45	-0.65
23-42	1.91	0.01	0.10	0.03	2.05	55.07	78.86	57.12	< 0.01	2	4	6.28	5.60	-0.68
42-60	1.99	0.01	0.18	0.03	2.21	47.07	67.04	49.28	< 0.01	3	4	6.40	5.80	-0.60
60-100	3.33	0.02	0.24	0.05	3.64	44.33	67.26	47.97	< 0.01	5	8	6.52	5.80	-0.72
100-130	3.51	0.02	0.37	0.05	3.95	39.75	48.93	43.70	< 0.01	8	9	7.00	6.00	-1.00
130-160	6.17	0.03	0.17	0.03	6.40	57.81	100.81	64.21	< 0.01	6	10	6.52	6.10	-0.42

(b)

Soil name: Niulii Classification: Hydric Dystrandepts, thixotropic, isothermic
Soil no.: 75HA-1-2 Location: North Kohala, Island of Hawaii, Hawaii

Depth	Horizon	Particle size analysis: Sand 2-.05	Silt .05-.002	Clay <.002	Bulk density	Water content: .1-bar	.3-bar	15-bar	Organic C	Total N	C/N	Extractable iron: Fe	Fe_2O_3
--cm---		pct < 2 mm			g/cc	pct			pct			pct	
0-17	Ap1								8.12	0.72	11	10.92	15.61
17-29	B21								5.04	0.39	13	11.42	16.33
29-48	B22								4.35	0.46	9	11.51	16.46
48-79	B23								5.52	0.40	14	8.18	11.69
79-107	IIC								4.04	0.66	6	4.25	6.08

Depth	Extractable bases: Ca	Mg	Na	K	Sum	Extractable acid	Cation-exchange capacity: NH_4OAc	Sum	Extractable Al	Base saturation: NH_4OAc	Sum	pH: H_2O	KCl	Difference
--cm---	meq/100 g soil									pct				
0-17	7.93	0.94	0.27	0.86	10.00	26.26	64.76	36.26	0.02	15	28	6.01	4.90	-1.11
17-29	0.38	0.01	0.23	0.07	0.69	46.60	56.21	47.29	0.68	1	1	5.22	4.56	-0.66
29-48	1.03	0.01	0.15	0.02	1.21	41.84	55.07	43.05	0.37	2	3	5.20	4.80	-0.40
48-79	0.17	0.01	0.10	0.04	0.32	56.61	80.54	56.93	0.29	< 1	< 1	5.20	5.02	-0.18
79-107	0.13	< 0.01	0.10	0.03	< 0.27	47.07	80.66	—	0.19	< 1	< 1	5.08	4.99	-0.09

Source: Ikawa, 1979.

Table 3.3 (continued) Some physical and chemical properties of the soils at four experimental sites: (a) Kukaiau, (b) Iole, (c) Molokai, (d) Waipio

(c)

Soil name: Lahaina taxadjunct Classification: Tropeptic Eutrustox, clayey, kaolinitic, isohyperthermic
Soil no.: 77HA-5-1 Location: Maunaloa, Island of Molokai, Hawaii

Depth	Horizon	Particle size analysis: Sand 2-.05	Silt .05-.002	Clay < .002	Bulk density	Water content: .1-bar	.3-bar	15-bar	Organic C	Total N	C/N	Extractable iron: Fe	Fe_2O_3
--cm---		------- pct < 2 mm -------			--g cc--	------------ pct ------------			----- pct -----			----- pct -------	
0-16	Ap1								3.73	0.28	13		
16-33	Ap2								1.72	0.10	17		
33-55	B21								1.02	0.18	6		
55-95	B22								0.70	0.08	9		
95-117	B23								1.17	0.09	13		
117-140	B24								0.91	0.04	23		
140-160	B25								0.84	0.04	21		

Depth	Extractable bases: Ca	Mg	Na	K	Sum	Extractable acid	Cation-exchange capacity: NH_4OAc	Sum	Extractable Al	Base saturation: NH_4OAc	Sum	pH: H_2O	KCl	Difference
--cm---	------------------------------ meq/100 g soil ------------------------------									------ pct ------				
0-16	5.52	2.29	0.15	2.07	10.03	9.96	19.54	19.99	0.05	51	50	5.49	4.88	-0.61
16-33	4.51	1.01	0.18	1.21	6.91	9.92	15.10	16.83	0.08	46	41	5.33	4.85	-0.48
33-55	4.45	1.26	0.17	0.38	6.26	5.71	12.18	11.97	—	51	52	6.14	5.62	-0.52
55-95	4.01	2.14	0.16	0.51	6.82	5.63	13.54	12.45	—	50	55	6.76	6.33	-0.43
95-117	3.13	1.77	0.15	0.92	5.97	5.28	16.24	11.25	—	37	53	6.12	5.73	-0.39
117-140	2.80	1.70	0.19	1.60	6.29	6.37	15.91	12.66	—	40	50	5.90	5.68	-0.22
140-160	2.82	1.79	0.35	1.09	6.05	7.38	10.17	13.43	<0.01	59	45	5.88	5.51	-0.37

(d)

Soil name: Wahiawa Classification: Tropeptic Eutrustox, clayey, kaolinitic, isohyperthermic
Soil no.: 77HA-7-1 Location: Waipio, Island of Oahu, Hawaii

Depth	Horizon	Particle size analysis: Sand 2-.05	Silt .05-.002	Clay < .002	Bulk density	Water content: .1-bar	.3-bar	15-bar	Organic C	Total N	C/N	Extractable iron: Fe	Fe_2O_3
--cm---		------- pct < 2 mm -------			--g cc--	------------ pct ------------			----- pct -----			----- pct -------	
0-10	Ap1	9.9	30.3	59.8					2.27	0.32	7	8.51	12.16
10-27	Ap2	8.5	28.6	62.9					1.72	0.26	7	7.52	10.75
27-40	AB	8.5	35.7	55.8					1.41	0.24	6	7.72	11.03
40-65	B21	8.2	39.4	52.4					0.59	0.14	4	8.10	11.58
65-90	B22	1.6	24.8	73.6					0.36	0.11	3	9.75	13.93
90-120	B23	4.2	20.9	74.9					0.27	0.08	3	7.30	10.43
120-150	B24	6.4	23.7	69.9					0.24	0.08	3	9.56	13.66

Depth	Extractable bases: Ca	Mg	Na	K	Sum	Extractable acid	Cation-exchange capacity: NH_4OAc	Sum	Extractable Al	Base saturation: NH_4OAc	Sum	pH: H_2O	KCl	Difference
--cm---	------------------------------ meq/100 g soil ------------------------------									------ pct ------				
0-10	6.52	4.35	0.17	2.69	13.73	9.16	20.81	22.89	0.03	66	60	5.41	4.80	-0.61
10-27	4.93	2.36	0.10	0.85	8.24	11.48	18.43	19.72	0.30	45	42	4.95	4.18	-0.77
27-40	6.07	3.05	0.12	0.11	9.35	9.93	17.58	19.28	0.05	53	48	5.31	4.48	-0.83
40-65	5.28	3.13	0.12	0.20	8.73	6.26	13.74	14.99	0.03	64	58	5.78	5.13	-0.65
65-90	4.78	3.64	0.13	0.23	8.78	5.15	13.01	13.93	—	67	63	6.12	5.61	-0.51
90-120	4.77	3.68	0.16	0.21	8.82	4.79	14.11	13.61	—	62	65	6.27	5.77	-0.50
120-150	5.19	3.46	0.36	0.38	9.39	4.71	14.42	14.13	—	65	66	6.37	5.85	-0.52

The variety used in the study was 'White Leaf'. The seeds were obtained from Zsang and Ma, Belmont, California.

Cassava belongs to the family Euphorbiaceae which also include para rubber. It is a short-lived shrub, 1-5 m in height, with latex in all its parts (Purseglove, 1974a). It is known for its edible roots, but young leaves are also consumed in different parts of the world. Leaves are variable in size, color of stipules, petioles, midribs and lamina, in number of lobes, depth of lobing and in shape and width of lobes. The cassava used in this study had leaves with 5-7 lobes, midribs and veins were green in color. The plants were approximately 2 m tall when the leaves were sampled.

Taro belongs to the Araceae family. Like cassava, it is well known for its starchy underground part and the leaves are also consumed in many parts of the world. The plants can grow to 1-2 m tall, with underground starchy corm, producing at its apex a whorl of large leaves with long erect petioles. The leaves are peltate, 20-50 cm long, oblong-ovate, glabrous, with rounded basal lobes. The petioles are stout, 1 m or more long and clasping at their bases (Purseglove, 1974b).

The variety used in this study was 'Miyako' which is probably native of Japan (Whitney et al., 1939). It is a short variety, shorter than 1 m, with erect and moderately stocky structure. The leaf blades are 35-50 cm long, 25-35 cm wide, 30-40 cm from tip to base of sinus, ovate, firm-chartaceous, dark green with a bluish cast, the lobes are wide and obtuse with shallow wide sinus.

3.3 Experiments

3.3.1 Amaranth field experiments

The field experiments were installed in Waipio, Iole and Kukaiau to represent a range of agroenvironments.

In addition to the effect of natural environmental factors on plant chemical composition, imposed management factors can also affect the nutrient and antinutrient contents of farm crops. Two factors which farmers frequently control are water supply and nutrient supply. To assess the effect of water supply on plant chemical composition, irrigated and non-irrigated experiments were conducted on each site. Water was supplied to the irrigated experiments with drip irrigation. The duration and frequency of irrigation were left to the discretion of project staff. In general, soil conditions were used as the main criterion to decide whether irrigation was required or not. Within each irrigation experiment, treatments to test the effect of nitrogen (N) or phosphorus (P) application on plant compositions were included. The fertilizer treatments consisted of:

1) a basal treatment of lime, N, P, K, bases and trace nutrients (Table 3.4),
2) a N treatment superimposed on the basal treatment designated basal+N (Table 3.5), and
3) a P treatment superimposed on the basal treatment designated basal+P (Table 3.5).

These fertilizer treatments were arranged in randomized complete block design with 3 replications within each irrigation treatment. Therefore, there were 9 plots of irrigated experiments and 9 plots of non-irrigated experiments. The plot size was 1.5 x 1 m^2.

Lime, epsom salt, borax and zinc sulfate (Table 3.4) were applied on an annual basis as a part of the routine operation of cropping systems experiments. These materials were applied before the amaranth experiments were installed. Urea, triple superphosphate and muriate of potash (Table 3.4) were applied 1-2 days prior to the planting of the amaranth. The lime rates were adjusted so that the resulting soil pH would be near pH 6. Higher lime rates were applied on Hydric Dystrandepts than on the Tropeptic Eutrustox (Table 3.4) because the former has a higher buffering capacity. The rates of various nutrients in the basal fertilizers applied (Table 3.4) were adjusted to provide adequate nutrients for good growth. The rates of N and P fertilizer applied at planting and as a sidedressing (Table 3.5) were calculated in such a way that the response of plants to these fertilizer treatments would be reflected in their yields and chemical compositions. A higher P rate was applied to the Hydric Dystrandepts soils than the Tropeptic Eutrustox soil because the former is known to fix P more than the latter. Response to P fertilizer was expected from plants grown on the Hydric Dystrandepts soil, while responses to N or both N and P were expected from plants grown on the Tropeptic Eutrustox soil.

At all locations the land was ploughed to 15 cm depth before the fertilizer was applied. All fertilizers used were of commercial grade. All basal fertilizers and lime (Table 3.4) and N and P fertilizers applied at planting (Table 3.5) were broadcast by hand before being worked into the soil. The plants were sidedressed with N fertilizer

(Table 3.5) after the plants had emerged and had been thinned to required spacing. The fertilizer was applied by hand, close to the plants and covered with soil.

Table 3.4

Forms and rates of basal fertilizers and lime used in the amaranth experiments

Element	Chemical formula (Common name)	Rate (kg element ha^{-1})	
		Hydric Dystrandepts	Tropeptic Eutrustox
Ca	$CaCO_3$ (lime)	1000	750
Mg	$MgSO_4.7H_2O$ (epsom salt)	100	100
B	$Na_2B_4O_7.10H_2O$ (borax)	5	2
Zn	$ZnSO_4.H_2O$	15	15
N	$CO(NH_2)_2$ (urea)	50	50
P	$CaH_4(PO_4)_2.H_2O$ (triple superphosphate)	25	25
K	KCL (muriate of potash)	170	100

After the application of lime, basal and preplant fertilizers, seeds were dropped by hand into furrows at 2.5 cm deep. No attempt was made to space the seeds as they were to be thinned to the required

Table 3.5

Rates and timing of application of N and P fertilizers in addition to basal in amaranth experiments

Site	Treatment	Rate (kg element ha^{-1})			
		Preplant (Basal)	At planting	Sidedress	Total
Iole and	N	50	100	100	250
Kukaiau	P	25	200	-	225
Waipio	N	50	100	100	250
	P	25	120	-	145

spacing later. There were 5 rows spaced 16.6 cm apart in each plot. The edge rows were used as guard rows.

In most cases the seeds emerged to form a thick stand. At the two- to four-leaf stage they were thinned to a linear density of one plant per 15 cm resulting in 11 plants per row leaving 55 plants per plot.

In Waipio, non-irrigated plots the plants did not emerge until approximately 2 months after sowing. Emergence followed 15 mm of rains which fell during March 8-15, 1983 and the growth was sustained by 54.1 mm of rains which fell from March 16 to April 27, 1983. The insecticide 'Sevin' was applied to all Waipio plants when they were approximately 1 month old to minimize insect damage. In Waipio, irrigated plots the plants emerged seven to ten days after seed sowing.

In Iole, plants in both the irrigated and non-irrigated treatments grew poorly. The seedlings emerged ununiformly and several weeks late and the plant growth was not uniform within the same plot. The emergence and growth were poorer in the irrigated plots than in the non-irrigated ones. However, the plants in both experiments did respond to P fertilizer treatment (basal+P) where the plants were larger than those receiving the other fertilizer treatments.

In Kukaiau, the plants in both irrigated and non-irrigated plots emerged uniformly and grew vigorously. Responses to fertilizer treatments, especially P, were clearly evident.

The experiments at each location were monitored by the project staff who also determined water requirements for the irrigated treatment. They also recorded the general conditions of the experiments.

The plants were harvested when the flower buds were apparent. An attempt was made to harvest the plants in all experiments at the same physiological stage. Due to the uneven emergence and growth in several treatments, all treatments were not harvested at the same time as shown in Table 3.6. The uneven emergence and growth rate resulted in exposures to different sets of environmental conditions for experiments conducted at the same site.

With the exception of the irrigated treatment at Iole, which produced less than 10 plants (Table 3.7), 10 representative plants from each plot (judged on their appearance, i.e., height, leaf and stem size, physiological stage such as appearance of flower buds), were sampled for analysis.

Table 3.6

Growing durations of amaranth grown in six experiments at three sites

	Kukaiau		Iole		Waipio	
	NI*	I*	NI*	I*	NI*	I*
Planting date	1/29/83	1/29/83	1/29/83	1/29/83	1/13/83	1/13/83
Harvesting date	4/10/83	4/10/83	5/4/83	6/28/83	6/23/83	3/24/83
Growing duration (days)	71	71	95	150	161	70
Number of plants harvested/plot	10	10	10	<10	10	10
Physiological stage and appearance at harvest	flower buds	flower buds	flower buds	flower buds, some at seeding stage	flower buds, small leaves	flower buds

*NI = Non-irrigated treatment. I = Irrigated treatment.

Table 3.7

Number of amaranth plants harvested from Iole, irrigated experiment

Plot #	Fertilizer treatment	Replication	No. of plants	Fresh weight (g)	Physiological stage
1	Basal	1	1	35	Seeding
2		2	1	232	Flowering
3		3	6	46	Flowering+seeding
4	Basal+N	1	6	256	Flowering
5		2	3	501	Flowering
6		3	0	0	-
7	Basal+P	1	9	833	Flowering
8		2	3	64	Flowering
9		3	4	134	Flowering

The plants were cut at the soil level and placed in polyethylene bags for transportation to the laboratory. At the laboratory, they were washed free of dust and soil with tap water and again with distilled water and blot-dried with paper towels. After washing and towel drying, they were weighed to obtain fresh weights.

The edible parts consisting of leaves and young succulent shoots, were separated from the 'non-edible', hard and fibrous stems and branches. The edible parts were stored in sealed polyethylene bags and stored in the freezers for later analysis.

3.3.2 Cassava

Cassava leaves were sampled from the Tropeptic Eutrustox soils at Waipio and Molokai and from the Hydric Dystrandepts soils at Kukaiau and Iole. At all sites cassava was grown in hedge rows as wind breaks for other crops in the cropping systems experiments as illustrated in Figure 3.1.

In the Waipio and Molokai sites casssava was grown in irrigated and non-irrigated plots, whereas in Kukaiau and Iole all plants were irrigated. Cassava is a drought resistant crop, therefore, it was expected to be able to thrive without irrigation in areas with low rainfall such as in Waipio and Molokai.

The youngest fully expanded leaves (i.e., the third or fourth leaf from the top) including petioles were harvested from each branch for a total of 50 leaves from each sampling location of the cropping pattern described in Figure 3.1. The 50 leaves from each location constituted a composite sample. Two composite samples were collected from each of two rows in Waipio and Molokai with Tropeptic Eutrustox soils, whereas three composite samples were collected from each of two rows in Kukaiau and Iole with Hydric Dystrandepts soils. Table 3.8 shows the age and sampling date of the cassava experiments.

The leaf samples were placed in plastic bags and transported to the laboratory where they were washed with tap and then distilled water to remove dust and soil, blotted-dried, weighed to determine fresh weights and frozen.

3.3.3 Taro

Taro leaves were sampled from the irrigated and non-irrigated plots at both the Kukaiau and Iole sites. No taro was grown at the Molokai site and all taro plants received irrigation water at Waipio owing to the low rainfall there.

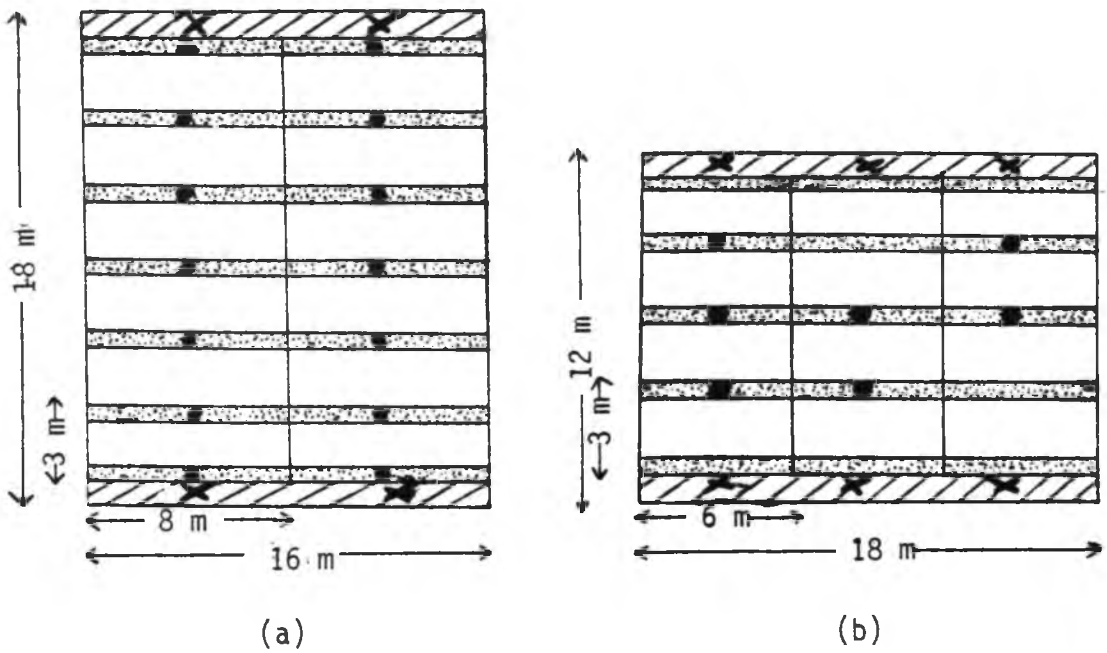


Figure 3.1 Cropping patterns for Tropeptic Eutrustox sites (a) and Hydric Dystrandepts sites (b) showing locations of cassava (▨) and taro (░) rows and sampling locations for cassava (X) and taro (●).

Table 3.8

Planting date, sampling date and age of cassava crops at sampling

Site	Planting date	Sampling date	Plant age (weeks)
Kukaiau	1/19/82	11/ 4/82	42
Iole	1/22/82	11/ 4/82	41
Waipio	2/17/82	11/ 1/82	37
Molokai	2/22/82	10/19/82	35

For analysis the youngest fully developed leaf was cut close to the blade to exclude the petiole. Each composite sample of eight leaves was collected from each row as of the cropping pattern described in Figure 3.1.

Fourteen samples were collected from the Waipio site and seven samples per experiment were collected from the Kukaiau and Iole sites for a total of 14 samples per site.

Table 3.9 gives the age and sampling date of the taro experiments. Each taro sample was cleaned and stored the same way as cassava leaves.

3.4 Laboratory analyses

This study involved many laboratory techniques, which were standardized and described in other publications and are mentioned briefly in this section. However, the fractionation of oxalates from plant tissue and their measurements by the high performance liquid chromatography (HPLC) technique was newly developed in this study in

Table 3.9

Planting date, sampling date and age of taro crops at sampling

Site	Planting date	Sampling date	Age at sampling date (weeks)
Kukaiau	4/13/82	11/4/82	29
Iole	4/14/82	11/4/82	29
Waipio	5/3/82	11/1/82	26

order to obtain data for objectives 1 and 3 of this study. The techniques are described in section 3.6.

3.4.1 Plant

Determination of dry weight and moisture content of plant tissue

To obtain moisture content of plant tissue (edible part) and at the same time to obtain dry plant material for chemical analyses, the frozen plant materials were freeze-dried at 40^{o}C. Freeze-drying is an effective technique to obtain dry plant material for analysis of organic compounds. Through this technique plant material can be dried at low temperatures thus avoiding changes in organic compounds.

The moisture contents of edible parts of amaranth were obtained by subtracting the freeze-dried weights from the frozen weights. Dry weights of harvested plants (10 plants) were then calculated from their fresh weights and the corresponding moisture contents. In the case of the Iole, irrigated plants, after the dry weight per plot was obtained, the value was adjusted to represent the 10 plants, because less than 10 plants were harvested from these plots (Table 3.7).

Moisture contents of cassava and taro were obtained by subtracting the freeze-dried weight from the fresh weight.

The freeze-dried plant materials were ground to fine powder for further chemical analyses.

Determination of sap pH

Approximately 1 g of freeze-dried ground plant material was mixed with 10 g of deionized water for pH measurement.

Determination of total nitrogen in plant tissue

Total-N in plant tissue was digested in a micro-Kjeldahl apparatus and measured by a colorimetric procedure using a Technicon autoanalyzer (Clements, 1980).

Determination of ionic and trace element contents in plant tissue

Concentrations of Cations (Ca, Mg, K, and Na) and anions (P ($H_3PO_4^-$), S (SO_4^{2-}), and Cl); and some trace elements including Al, Mn, Zn, Cu, Fe and Si were determined by a x-ray fluorescence spectrometer, model 72,000 manufactured by Applied Research Laboratories.

Nitrate-N was determined by the H_2SO_4-salicylic acid method (Cataldo et al., 1975). Boron was determined by automated carminic acid-phenol method (Clements, 1980). The technicon autoanalyzer was used as the main analytical apparatus for both nitrate-N and B determinations.

The concentrations of all major cations and anions were expressed in the units of cmol kg^{-1} on a dry weight basis which is identical to the unit of me/100 g on a dry weight basis, for comparative (ionic balance study) purposes and as percent of dry weight for general quantitative purposes.

Determination of oxalate in plant tissue

This consisted of the extraction of the total as well as various fractions of oxalate and the subsequent measurement of oxalic acid concentrations by the HPLC technique. The detailed procedures are described in section 3.6.

The concentrations of oxalates were expressed in cmol kg^{-1} on a dry weight basis and percent of dry weight for the purposes stated earlier.

Determination of bases in the oxalate fractionation extracts of plant tissue

The water soluble fraction and water insoluble but acid soluble fraction were analyzed for Ca, Mg, K and Na concentrations. Ca and Mg were determined in an atomic absorption spectrophotometer (Perkin and Elmer Model 303) and K and Na on a flame photometer (Coleman Junior II, Model 6/20). The concentrations were expressed as cmol kg^{-1} on a dry weight basis.

3.4.2 Soils

To characterize the agroenvironment further, soil chemical analyses for their total N, exchangable bases and P contents were conducted. Soil samples from only the amaranth plots were chemically analyzed. Soil data for cassava and taro were obtained from the soil analysis of 1983 of the Benchmark Soils Project.

Determination of total-nitrogen in soils

The total-N in soils was determined using the micro-Kjeldahl method (Soil Conservation Service USDA, 1972). Soil samples weighing 0.5-1 g and a catalyst mixture of K_2SO_4:$FeSO_4$:$CuSO_4$:Se=7.9:1:1:0.1 by weight were used. Ammonia was collected in boric acid and titrated with 0.0371 or 0.0519 N H_2SO_4 depending on the N concentrations. This method of total-N determination did not include NO_3-N.

Determination of exchangeable bases in soils

Exchangeable bases (i.e., Ca, Mg, K and Na) were extracted from 10 g of air-dried soils with 15 ml of 1 N NH_4OAc. After the extract was filtered, the filtrate volume was made up to 100 ml (Soil Conservation Service USDA, 1972). Calcium and Mg were determined by atomic absorption spectrophotometry and K and Na by flame photometry.

Determination of extractable phosphate in soils

One gram of oven-dried soil was extracted with 100 ml of modified Truog extractant (0.025 N H_2SO_4+0.38% $(NH_4)_2SO_4$). Phosphorus concentration was determined colorimetrically using ammonium paramolybdate and ascorbic acid as color developer (Ayres and Hagihara, 1952; Olsen and Sommers, 1982).

3.5 Data analysis

The Statistical Analysis System (SAS) computer package was used for the analysis of variance, means comparisons and correlation and regression analyses.

In amaranth, the fertilizer treatments within each irrigation experiment were arranged in a randomized complete block design and analyzed accordingly. The effects of irrigation, fertilizer and their interactions at each site were analyzed as if the experiment was a split plot design with irrigation as the main plots and fertilizer treatments as the subplots. The difficulty in randomizing the irrigation treatment necessitated this approach and therefore the interpretation of the statistical analysis requires some caution.

The effects of sites and various interactions were analyzed using the split split plot design with site as the main plots, irrigation as the subplots and fertilizer as the sub-subplots.

For the cassava study, all sites had irrigated experiments but only the Molokai and Waipio sites had both irrigated and non-irrigated trials. In the taro study, the Kukaiau and Iole sites had both irrigated and non-irrigated experiments wheras the Waipio site had only irrigated experiments. No taro experiment was conducted at the Molokai site. Since the irrigated experiments were conducted at all sites, the effect of site on plant chemical composition was tested on data collected from the irrigated experiments.

The effect of irrigation was analyzed for each site containing both types of experiments, and the effect of site by irrigation interaction was obtained by combining the irrigated and non-irrigated cassava experiments from the Waipio and Molokai sites and by combining the irrigated and non-irrigated taro experiments from Kukaiau and Iole.

The Duncan-Waller's multiple range test was used for comparing the effects of site and fertilizer on amaranth and the effect of site on cassava and taro. This test is appropriate for cases with unequal subclass numbers as was the case with the cassava and taro experiments.

In order to evaluate results affected by treatment interactions, the least significant difference (LSD) analysis was employed because the Duncan-Waller's multiple range tests only compare main effects.

The relationships between various plant, soil and weather variables were investigated through correlation and regression techniques. Multiple regression models were used to assess the effects of climatic and soil variables on oxalate and nitrate contents of amaranth, cassava and taro.

3.6 Development of methods for oxalate extraction, fractionation and determination

The development of these methods was designed to meet the conditions for organic acid determination by high performance liquid chromatography (HPLC).

3.6.1 Extraction of total oxalate from plant tissue

This was essentially the standard technique described in AOAC (Horwitz, 1975) with minor modifications.

Freeze-dried, finely ground plant material weighing 2.5 g was boiled for 30 minutes in 300 ml of 1.1 N HCl (55 ml 6 N HCl and 245 ml distilled water). Two to three drops of caprylic alcohol were added to prevent foaming during boiling.

The boiled mixture was allowed to cool to room temperature, and its volume subsequently adjusted to 500 ml with distilled water. It was, then, filtered through Whatman #541 filter paper. The first 100 ml of the filtrate was discarded and the remaining filtrate was stored in a refrigerator at 4^{o}C for subsequent oxalate determination by the HPLC technique.

3.6.2 Extraction of oxalate fractions

Previous findings, such as those of Baker (1952), Moir (1953), Singh and Saxena (1972) and Hodgkinson (1977), suggest that oxalates should be fractionated into 3 parts, namely, free oxalic acid, hot water soluble oxalate and hot acid soluble (hot water insoluble) oxalate.

Free oxalic acid is known to be highly soluble in ethanol at room temperature, while the other forms of oxalate, such as K-, Ca-, Mg-, Na- and NH_4-oxalates are insoluble (Weast, 1973). Thus, ethanol was used to extract free oxalic acid.

Potassium-, Na-, NH_4-oxalates and to a lesser extent, Mg oxalate are known to be water soluble and their solubilities increase with increasing temperature (Weast, 1973; Hodgkinson, 1977). Boiling water was, therefore, used to extract this fraction.

Calcium oxalate and to a lesser extent Mg oxalate are known to be relatively insoluble in water (Weast, 1973; Hodgkinson, 1977). Therefore, hot acid, similar to that used to extract total oxalate, was used to extract this fraction.

Procedure for extraction of oxalate fractions

Freeze-dried, finely ground plant material weighing one gram was shaken for one hour in 30 ml of 95% ethanol. The mixture was filtered through ashless filter paper and subsequently washed with ethanol. The filtrate was made to 100 ml volume with ethanol. This extract was used for free oxalic acid determination.

The plant residue on the filter paper was dried to room temperature, and was transferred into a 600 ml beaker. One hundred ml of distilled water were added to the beaker along with two to three drops of caprylic alcohol to prevent foaming. The mixture was boiled for 30 minutes. After cooling to room temperature, it was filtered through fast, ashless filter paper into a 200-ml volumetric flask. The volume was made up with distilled water. This extract was used for the determination of water soluble oxalate, Ca, Mg, K, and Na contents.

The wet plant residue on the filter paper was transferred to a 1000-ml beaker along with 150 ml of distilled water, 27.5 ml 6 N HCl and a few drops of caprylic alcohol. The mixture was boiled for 30 minutes. After cooling to room temperature, the content was poured into a 250-ml volumetric flask and the volume was made up with distilled water. The content in 250-ml volumetric flask was filtered through fast, ashless filter paper (Whatman #541). The first 100 ml of the filtrate was discarded and the remainder was kept for determination of insoluble oxalate, Ca, Mg, K, and Na contents.

3.6.3 Preparation of the samples from the different oxalate fraction for HPLC analysis

An aliquot of 1-2 ml from each extract was pipetted into a test tube. With the exception of the alcohol extract, all aliquots were evaporated to dryness in a vacuum oven at 40-42°C. This process took approximately 5-8 hours. The aliquots from the alcohol extract were evaporated in an air convection oven at 40°C. The dry residues were dissolved in 10 ml of 0.013 N H_2SO_4 since this acid was also used as the standard eluent (mobile phase) for the ion exchange column of the HPLC.

After each residue was dissolved in 0.013 N H_2SO_4, the solution was filtered through Whatman #1 filter paper and refiltered through a special filter 'Sep Pak', manufactured specifically for HPLC use. The solution prepared from ethanol extract required several refilterings with 'Sep Pak' (Water Assoc., Mass.) to remove color. The final solution prior to analysis by HPLC was clear and colorless. The samples were frozen if an immediate HPLC run was not possible.

3.6.4 Description of oxalate determination by HPLC technique

The instrument which is called collectively HPLC consisted of an automatic injector, a high pressure pump, a chromatographic column, a detector and an integrator.

The automatic injector (Micromeritics Model 725, Norcross, Georgia 30093) enables the samples to be fed to the system automatically. Approximately 0.8 ml was required from each sample. The samples were placed in special glass vials with a tightly fitting plastic stopper. The stoppered vials containing the samples were arranged in a self-revolving tray attached to the injector. A needle which automatically penetrated the plastic stopper of the vial fed sample solutions to the column.

The column pressure was maintained between 1500-1850 psi with a Beckman solvent metering pump, Model 110A. The pressure is determined by the flow rate and the chemical nature of the mobile phase. In most cases the flow rate was maintained at 0.6-0.8 ml/minute.

The chromatographic column is known as an 'ion exchange column'. It detects and measures organic acids by ion exclusion and partition chromatography by means of a strong cation exchange resin Aminex ion exclusion HPX-87, manufactured by BIO-RAD. In general, organic acids emerge from the column in the order of increasing pKa when dilute sulfuric acid is used as the solvent.

The detector used was a combination of the Model 100-10 Hitachi spectrophotometer and Beckman's Altex spectrophotometer flow cells. The combination results in a high performance variable wavelength absorbance detector for use in liquid chromatography. For organic acid analysis, the UV wavelength of 210 nm was used.

A small, single-channel plotting/reporting integrator Model 3390A Hewlett and Packard was also a part of the assembly.

Minor modification of the procedures

High nitrate content in the leaf tissue interfered with oxalate determination by the HPLC column. Nitrate and oxalate have the same absorbance wavelength (210 nm) and their retention times are very close, especially when 0.013 N H_2SO_4 is used as the eluent. This eluent did not permit the complete separation of oxalate and NO_3. Better separation was achieved when more concentrated sulfuric acid (i.e., 0.05 N) was used. However, when the column was replaced with a new one of the same specification, it was found that 0.05 N H_2SO_4 by itself was not sufficient to separate NO_3 and oxalate. The use of 5% acetonitrile with 0.05 N H_2SO_4 resulted in better separation of oxalate and NO_3. However, acetonitrile shortened the life span of the column.

Use of an internal standard to study oxalate recovery from HPLC determination

During each HPLC run, recovery study was run simultaneously, by using an 'internal standard'. For this purpose, 0.1 ml of 1,000 ppm standard oxalic acid was added to a two ml aliquot of plant extract. This 'spiked' sample (Figure 3.2) was run in duplicate. The rest of the procedure remained the same as described in section 3.6.3. The 10 ml spiked sample (section 3.6.3) contains oxalic acid from the plant extract and internal standard. As shown in Figure 3.2, the addition of 0.1 ml of 1,000-ppm oxalic acid should result in a 10 ppm higher concentration for 100% recovery.

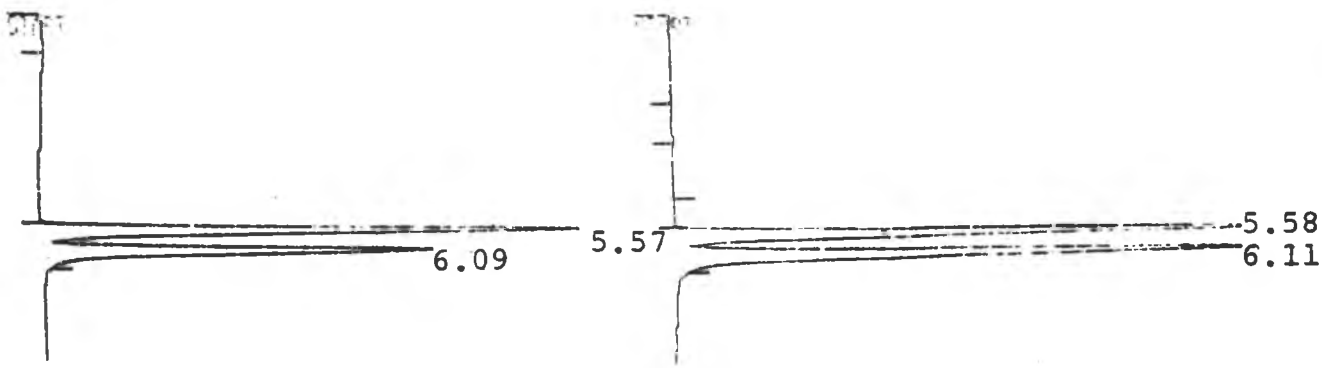
The percent recovery was calculated by taking the difference in oxalate concentration between the spiked and non-spiked sample. This difference divided by the concentration of the added internal standard is the fraction recovered. This value was used to adjust all HPLC reading to 100% oxalate recovery.

3.6.5 Comparison of the classical and HPLC methods of oxalate determination

In order to measure the several forms of oxalate in plant tissue, it is necessary to use sensitive methods of analyses. In this experiment the recoveries of various forms of oxalate using the classical and HPLC methods of oxalate determination were compared. Analytical grades of oxalic acid and three forms of oxalate were used to prepare a range of solution concentrations as shown in Table 3.10. Aliquots of these working standards were analyzed by both the HPLC and classical methods.

The classical procedure

The classical technique for oxalate determination (Horwitz, 1975) is based on the precipitation of oxalate in the plant extract as Ca



Run #517

RT*	Area	Amount (ppm)
5.57	691950	3.394
6.09	563130	21.481

'Non-spiked'

Run #518

RT*	Area	Amount (ppm)
5.58	818160	4.013
6.11	826990	31.546

'Spiked'

Figure 3.2 HPLC chromatograms illustrating the resolution of nitrate (upper) and oxalate peaks and the difference between spiked (right) and non-spiked samples.

*RT = Retention time in minutes.

Table 3.10

Standard solutions of oxalic acid and oxalates

Form	Formula and formula weight	Concentration of oxalate ion ($C_2O_4^{2-}$) (ppm)					
Oxalic acid	$HOCOCOOH.2H_2O$ (126.00)	1000	500	250	125	62.5	6.3
Sodium oxalate	$Na_2C_2O_4$ (134.00)	656.7	328.4	164.2	82.1	41.0	4.1
Ammonium oxalate	$(HH_4)_2C_2O_4.H_2O$ (142.12)	709.0	345.5	177.2	88.6	44.3	4.4
Potassium oxalate	$K_2C_2O_4.H_2O$ (184.24)	529.4	264.7	132.3	66.2	33.1	3.3

oxalate at pH 4 to 5, and the subsequent titrimetric or spectrophotometric determination of Ca.

An aliquot of 20 ml of each standard oxalate solution shown in Table 3.10 was pipetted into a beaker. The pH of the aliquot was adjusted to 4-4.5 with concentrated NH_4OH. Then, 5 ml of a calcium oxalate solution in acetate buffer (pH 4.5) were added. The mixture was allowed to stand overnight at room temperature to provide enough time for Ca oxalate to precipitate. This was centrifuged at 3,000 rpm for 15 minutes. After removal of the supernatant liquid, the precipitate was washed twice with a fine jet stream of 20 ml filtered, cold 'wash liquid'. Five ml of 10% H_2SO_4 were added to dissolve the Ca oxalte and the contents quantitatively transferred and made to volume in a 25-ml volumetric flask with 1 N HCl. The Ca in this solution was measured by atomic absorption spectrophotometer.

The HPLC procedure

The standard oxalic acid and oxalate solution (Table 3.10) were analyzed directly without sample preparation because of their high purity. The resulting peak heights are shown in Table 3.11 and related to oxalate concentration as illustrated in Figure 3.3.

As shown in Table 3.12, the classical method gave good results between the range of 325-700 ppm but overestimated oxalate content below 300 ppm and underestimated the true value above 700 ppm.

The HPLC method resulted in a curvilinear relationship between peak height and oxalate ion concentrations (Figure 3.3). A linear relationship was found between 0-125 ppm (Figure 3.3). The particular chromatographic column used in this experiment could not detect oxalic acid below 6.3 ppm (Table 3.12), but throughout much of this study there was evidence that this technique could determine oxalic acid concentrations as low as 2 ppm. Different forms of oxalate salts had little effect on the accuracy of oxalate determinations for both techniques.

This study shows that the HPLC is a good method for plant oxalates because the concentration range in plant extract samples (10-100 ppm) falls within the linear range.

Table 3.11

Relationships between oxalate ion ($C_2O_4^{2-}$) concentrations and HPLC peak height

$C_2O_4^{2-}$ concentration (ppm)	Peak height (cm)
33.1	0.9
41.0	1.0
44.3	1.2
62.5	1.7
66.2	1.8
82.1	2.2
88.6	2.4
125.0	3.3
132.3	3.9
164.2	4.8
177.2	5.2
250.0	7.4
264.7	8.8
328.4	11.0
354.5	12.5
500.0	16.4

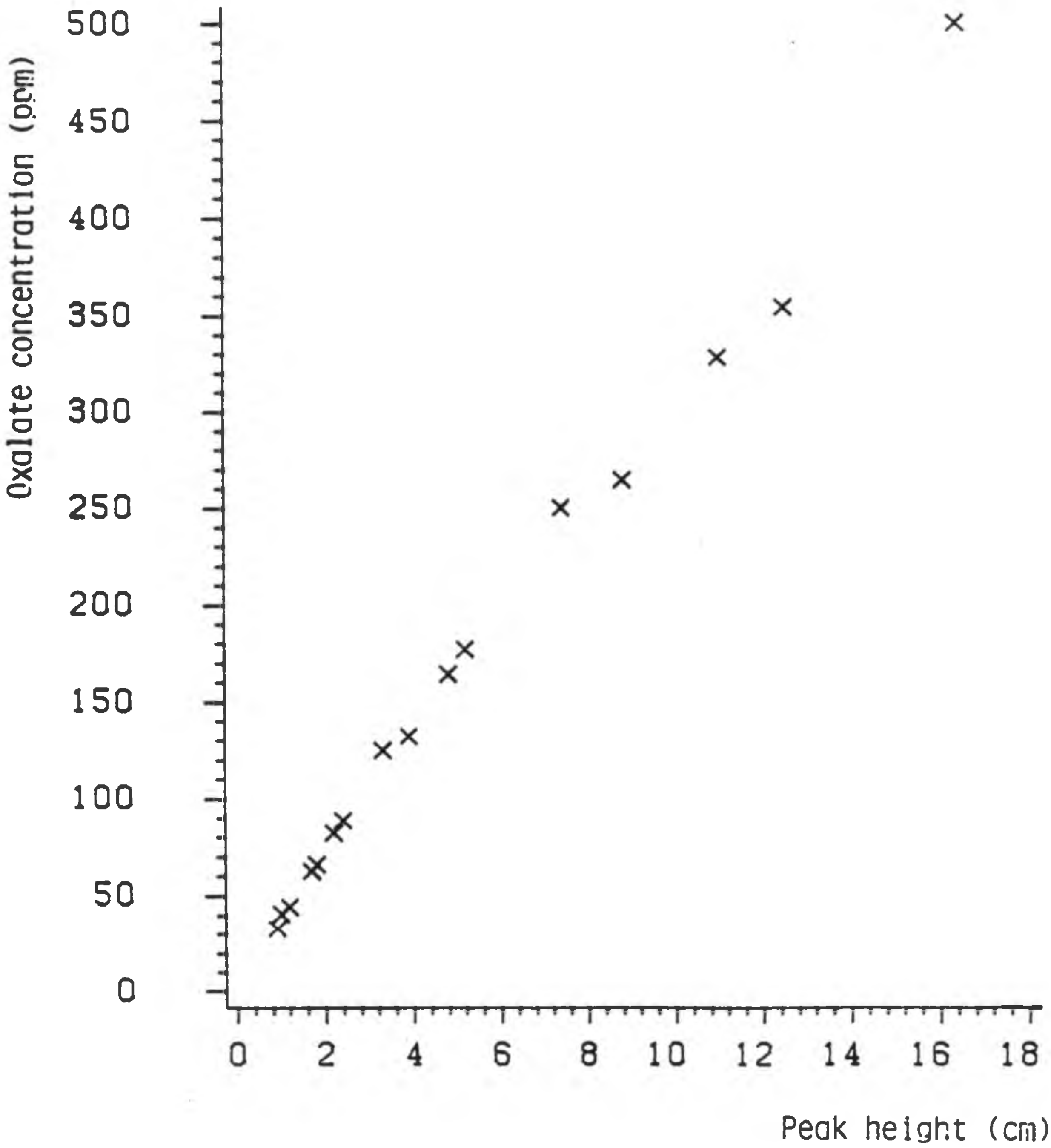


Figure 3.3. Relationship between oxalate concentration and peak height.

Table 3.12

Comparison of oxalate content determined by the classical and HPLC methods

	Oxalate ion ($C_2O_4^{2-}$) concentration (ppm)		
	Standard concentration	Measured concentration	
		Classical	HPLC*
Na oxalate	656.7	663.4	-
	328.4	329.7	336.2
	164.2	192.5	157.6
	82.1	101.5	82.5
	41.0	-	37.5
	4.1	-	n.d.**
NH_4 oxalate	709.0	718.1	-
	354.5	350.6	378.2
	177.2	215.8	169.4
	88.6	120.0	90.0
	44.3	-	45.0
	4.4	-	n.d.
K oxalate	529.4	551.0	-
	264.7	275.8	273.8
	132.3	157.8	131.0
	66.2	90.6	67.5
	33.1	-	33.8
	3.3	-	n.d.
Oxalic acid	1000	840.0	-
	500	476.2	485.3
	250	265.7	233.5
	125	140.5	123.8
	62.5	-	63.8
	6.3	-	n.d.

* The regression equation, $y = 0.1906 + 37.3293x$, in Figure 3.3 was used to calculate oxalate concentrations below 125 ppm, but $y = 13.83 + 30.46\,x - 0.10\,x^2$ was used for concentrations greater than 125 ppm.

** Non-detectable due to exceedingly low concentrations.

3.6.6 Oxalate recovery from the extraction and fractionation of plant materials

This part of the study consisted of three parts which are called Recovery I, Recovery II and Mg oxalate solubility. The Recovery I experiment was conducted for the purpose of assessing the recovery of total, Ca-, K- and Mg oxalates from plant material using the total oxalate extraction and oxalate fractionation techniques described in sections 3.6.1 and 3.6.2. Since Mg oxalate is partially soluble in hot water, the Recovery II experiment was conducted for the purpose of assessing the recovery of only the total, Ca-, and K oxalates from plant material using the technique described in sections 3.6.1 and 3.6.2. Concentrations of the internal standards used for these recovery studies are given in Table 3.13.

Based on published chemical data (Weast, 1973), three assumptions were made: (1) that K oxalate was totally soluble in boiling water, (2) that Ca oxalate was totally insoluble in hot water but was totally soluble in hot acid, and (3) that Mg oxalate was partially soluble in hot water and also soluble in hot acid.

A magnesium oxalate solubility experiment was conducted to measure the proportion of Mg oxalate which is soluble in hot water and in hot acid. The results from this experiment were used to calculate recovery of Mg oxalate in the recovery I experiment. The two recovery experiments made use of added internal standards as described in section 3.6.4. The experiment included a set of 'controls' which did not receive oxalate internal standards. The difference in oxalate concentration between the treated and the control samples was the added concentration of internal standards to the 'treated' samples. Recovery was calculated as follows:

$$\% \text{ recovery} = \frac{\text{ppm of 'treated' sample - ppm of 'control' sample}}{\text{Actual concentration (ppm) of oxalate internal standard added}} \times 100$$

Magnesium oxalate solubility experiment

Three replications of 0.0659 g of analytical grade Mg oxalate ($MgC_2O_4.2H_2O$) were weighed and placed in 250-ml beakers. One hundred ml of distilled water, a volume equal to the amount used to extract water soluble oxalate fractions were added to the beakers. The contents were boiled for 30 minutes, cooled to room temperature, filtered through #40 Whatman filter paper into a 200-ml volumetric flask and made up to volume with distilled water. This is the same treatment that was used for plant samples except that #40 filter paper was used here.

A 1 ml aliquot was diluted 25 times with distilled water and magnesium was determined in this solution by atomic absorption spectrophotometry.

The Mg concentration was converted to an equivalent amount of Mg oxalate. This portion of Mg oxalate was considered to be water soluble. By subtracting this soluble portion from the total Mg oxalate originally added, the quantity of water insoluble portion was obtained.

On an average 72.1% of the $MgC_2O_4.2H_2O$ was soluble in boiling water while 27.9% was insoluble (Table 3.14). These percentages were taken to represent the solubility of plant Mg oxalate. However, it should be emphasized that this experiment did not simulate the true conditions of plant samples where other oxalates might interfere with the solubility of Mg oxalate. The solubility obtained with reagent grade Mg oxalate may overestimate the solubility of Mg oxalate in plant materials and underestimate the amount of insoluble Mg oxalate.

Recovery I experiment

Dried, ground plant material weighing 1 g was transferred to a 250-ml beaker. Care was taken to keep sample weights between 1.0000± 0.0001 g to allow for direct computation of recovery from HPLC reading in ppm. For the 'treated' samples, internal standards of 0.0409, 0.0324 and 0.0658 grams of K-, Ca- and Mg oxalates, respectively were added. These quantities were pre-calculated to enable the final oxalte concentration to be read directly from the HPLC.

The results showed that recoveries of the water soluble fraction and total oxalate were low, while the insoluble fraction exceeded 100% (Table 3.15). These results appear to support the concern regarding the decreasing effect that plant oxalates could have on the recovery value of Mg oxalate determined on the pure reagent grade salt.

Recovery II experiment

To eliminate the uncertainty regarding the solubility of Mg oxalate in boiling water, the addition of Mg oxalate crystals were excluded in the Recovery II experiment. The procedures, otherwise, were the same as those of the recovery I experiment.

The recoveries of oxalate in the water soluble and water insoluble fractions were close to 100% (Table 3.16). These recoveries are considered satisfactory and indicate that all K oxalate and Ca oxalate are recoverable by the methods of fractionation and extraction employed in this study.

Table 3.13

Concentrations of internal standards for three forms of oxalate used in the recovery experiment

Oxalate fractions	K oxalate (a)	Ca oxalate (b)	Total for Recovery II (a)+(b) (ppm)	Mg oxalate (c)	Total for Recovery I (a)+(b)+(c)
Soluble oxalate	16.0	0.0	16.0	11.5*	27.5
Insoluble oxalate	0.0	8.0	8.0	4.5	12.5
Total oxalate	16.0	8.0	24.0	16.0	40.0

*Using 72.1% solubility value.

Table 3.14

Solubility of magnesium oxalate in hot water

Portion of Mg oxalate	Mg oxalate	
	mg	% total
Total amount added	65.8	100.0
Boiling water soluble	46.5	72.1
Boiling water insoluble (acid soluble)	19.4	27.9*

*A preliminary experiment showed that Mg oxalate was completely soluble in hot acid.

Table 3.15

Recovery of water soluble, water insoluble and total oxalate (Recovery I experiment)

Treatments	Oxalate concentrations in different fractions			
	Water soluble (1)	Water insoluble (2)	Total (1)+(2)	Total analyzed
Treated[a] (ppm)	22.9	50.9	73.8	70.3
Control[a] (ppm)	13.5	26.6	40.4	41.2
Difference[a] (ppm)	9.4	24.3	33.7	29.1
Recovery (%)[a]	34.2[b]	194.4[c]	84.3[d]	72.8

a Means of 3 replicates
b Calculation: (9.4/27.5) x 100
c Calculation: (24.3/12.5) x 100
d Calculation: (33.7/40.0) x 100

Table 3.16

Recovery of water soluble, water insoluble and total oxalate (Recovery II experiment)

Treatments	Oxalate concentrations in different fractions			
	Water soluble (1)	Water insoluble (2)	Total (1)+(2)	Total analyzed
Treated[a] (ppm)	36.2	48.8	85.0	87.2
Control[a] (ppm)	19.3	40.6	59.9	61.6
Difference[a] (ppm)	16.9	8.2	25.1	25.6
Recovery (%)[a]	105.6[b]	102.5[c]	104.6[d]	106.7

a Means of 3 replicates
b Calculation: (16.9/16.0) x 100
c Calculation: (8.2/ 8.0) x 100
d Calculation; (25.1/24.0) x 100

3.7 Soil and weather characteristics measured specifically for the study of agroenvironmental effects on nutritional quality of food crops

In order to characterize the agroenvironment of the experimental sites, measurement of soil and climatic components of the agroenvironments were undertaken at each site. Soil data from amaranth experiments were obtained for each experimental plot, but those from cassava and taro experiments were already measured and made available by the Benchmark Soils Project.

The chemical analysis of the soil samples from amaranth plots were made after the plants were harvested. The results of the chemical analysis of the soil for the amaranth, cassava and taro (Tables 3.17, 3.18) plots are comparable to the previous results of soil analysis from the same sites (Table 3.3) reported by Ikawa (1979). The Tropeptic Eutrustox soils in Molokai and Waipio had higher exchangeable bases than the Hydric Dystrandepts soils of Iole and Kukaiau as shown in Tables 3.17 and 3.18. On the other hand, the Tropeptic Eutrustox soil at Waipio had significantly lower total N content than the Hydric Dystrandepts soils of Iole and Kukaiau (Table 3.17). Higher P contents were found in the Kukaiau soil than the soils from the other sites as shown in Tables 3.17 and 3.18. This was likely residual P from previous heavy P applications on the Kukaiau soil.

Since the irrigated and non-irrigated plots were not situated adjacent to each other in all three sites of amaranth experiments, the soil chemical properties of both irrigated and non-irrigated plots are presented in Table 3.19. In Kukaiau, higher total N and P were found in the irrigated than in the non-irrigated plots. In Iole, higher total N was found in the irrigated plots but higher Ca and Mg concentrations were found in the non-irrigated plots. In Waipio, higher concentrations of Na and P were found in the irrigated plots, but Ca and K were higher in the non-irrigated plots. The difference in soil chemical properties between irrigated and non-irrigated plots can result in differences in plant chemical composition.

There are distinct differences regarding the climatic factors of the four experimental sites. Kukaiau and Iole sites are generally wetter than the Waipio site (Tables 3.20, 3.21, 3.22). However, the Molokai site, although considered to be a dry site due to low rainfall, had a higher relative humidity than the other three sites (Table 3.21).

The Kukaiau and Iole sites received lower solar radiation and had lower air and soil temperatures than the Molokai and Waipio sites (Tables 3.20, 3.21, 3.22). Both Kukaiau and Iole sites were situated in higher elevations and because of the frequent cloud cover associated with frequent rains and cool temperatures, the energy supply was lower compared to the Waipio and Molokai sites.

Comparing the two sites at the Island of Hawaii, Iole tended to be cooler as indicated by lower air and topsoil temperatures and solar radiation (Tables 3.20, 3.21, 3.22). Since the non-irrigated amaranth in Waipio were left in the field much longer than its irrigated counterpart, it received almost 5 times more rain than the irrigated amaranth (Table 3.20). A similar situation was observed in Iole since irrigated and non-irrigated plants were harvested at different times.

Table 3.17

Chemical analysis of soils at three different experimental sites used for the amaranth experiments

Location	total N	P	Ca	Mg	K	Na
	%	ppm	cmol kg^{-1} soil			
Kukaiau	0.55 A	81.2 A	2.4 C	1.0 C	0.25 C	0.09 B
Iole	0.48 B	72.9 B	3.3 B	1.2 B	0.32 B	0.09 B
Waipio	0.18 C	78.3 AB	5.6 A	3.4 A	0.74 A	0.43 A

*Means in the same column with the same letters are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

Table 3.18

Concentrations of some nutrients in soils at each experimental site of cassava and taro experiments

Site	cmol kg^{-1} soil				ppm
	Ca	Mg	K	Na	P
Molokai	4.6	2.0	1.3	0.20	20.2
Waipio	3.3	3.5	2.1	0.23	81.4
Iole	3.4	1.4	0.6	0.07	83.8
Kukaiau	2.6	0.9	0.4	0.07	110.1

Table 3.19

Soil chemical analysis results of irrigated and non-irrigated plots of three experimental sites

Site	Treatment*	Total N %	P ppm	Ca	Mg	K	Na
				cmol kg^{-1} soil			
Kukaiau	NI	0.54	74.3	2.4	0.9	0.23	0.08
	I	0.56	88.0	2.4	1.0	0.27	0.11
Significance level (F-test)		0.0016	0.0270	0.7231	0.4641	0.5386	0.1637
Iole	NI	0.45	75.6	4.0	1.4	0.32	0.11
	I	0.50	70.2	2.5	1.0	0.31	0.06
Significance level (F-test)		0.0003	0.1459	0.0001	0.0004	0.7053	0.1864
Waipio	NI	0.18	70.7	5.9	3.3	0.99	0.11
	I	0.17	85.9	5.3	3.5	0.49	0.77
Significance level (F-test)		0.2920	0.0426	0.0120	0.1597	0.0001	0.0001

*NI = non-irrigated
I = irrigated

Table 3.20

Weather characteristics during the growing period of amaranth grown at three sites

Site	Irrigation	Air temperature[a] (°C)			Soil temperature[a] (°C)						Relative humidity[a] (%)			Cumulative rainfall[b] (mm)	Solar radiation[a] (Langley)	Wind speed[a] (km/hr)
					Topsoil			Subsoil								
		Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave			
Waipio	NI	27.3	15.7	21.5	21.1	20.4	20.8	21.9	21.7	21.8	78.7	45.6	62.2	115.6	768.2	7.2
	I	27.0	14.6	20.8	20.3	19.9	20.1	21.7	21.4	21.6	79.5	44.4	62.0	35.7	696.2	7.1
Iole	NI	22.9	13.2	18.1	18.8	18.1	18.5	20.4	20.1	20.3	90.0	55.6	72.8	332.0	363.6	4.1
	I	23.0	13.4	18.2	19.1	18.5	18.8	20.6	20.3	20.5	90.1	57.9	74.0	440.4	371.9	5.9
Kukaiau	NI & I	25.9	16.5	21.2	20.3	19.3	19.8	19.0	19.0	19.0	80.1	50.9	65.5	293.0	391.4	5.0

[a]Average daily values

[b]Cumulative values for the whole growing period

Table 3.21

Weather characteristics during the period from planting to sampling of cassava grown at four sites

Site	Air temperature[a] (°C)			Soil temperature[a] (°C) Topsoil			Soil temperature[a] (°C) Subsoil			Relative humidity[a] (%)			Cumulative rainfall[b] (mm)	Solar radiation[a] (Langley)	Wind speed[a] (km/hr)
	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave			
Molokai	28.7	20.5	24.6	21.5	21.1	21.3	22.0	21.8	21.9	97.8	71.0	84.4	441.9	510.0	19.0
Waipio	29.6	19.3	24.5	22.9	22.3	22.6	23.6	23.3	23.5	85.0	53.6	69.3	843.8	481.4	7.6
Iole	24.4	16.3	20.4	20.7	19.7	19.9	21.0	20.4	20.7	90.9	63.8	77.4	2354.8	351.9	9.8
Kukaiau	25.0	17.6	21.3	22.2	21.0	21.6	20.5	20.5	20.5	85.5	64.9	75.2	3088.6	370.7	8.1

[a]Average daily values

[b]Cumulative values from planting to sampling

Table 3.22

Weather characteristics during the period from planting to sampling of taro grown at three sites

Site	Air temperature[a] (°C)			Soil temperature[a] (°C) Topsoil			Soil temperature[a] (°C) Subsoil			Relative humidity[a] (%)			Cumulative rainfall[b] (mm)	Solar radiation[a] (Langley)	Wind speed[a] (km/hr)
	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave			
Waipio	31.2	19.9	25.6	23.8	23.2	23.5	24.4	24.0	24.2	84.1	51.8	68.0	585.0	533.5	6.9
Iole	24.8	16.6	20.7	20.9	20.4	20.7	21.7	21.5	21.6	90.7	64.9	77.8	1363.6	372.5	9.5
Kukaiau	25.9	18.6	22.2	23.3	22.0	22.7	21.3	21.3	21.3	85.3	65.8	75.5	1485.5	392.4	8.8

[a]Average daily values

[b]Cumulative values for the period from planting to sampling

CHAPTER IV

RESULTS AND DISCUSSION

The hypothesis to be tested is that the nutrient and antinutrient content and therefore the overall composition of food crops, are affected by controlled and uncontrolled environmental factors that regulate crop growth, development, and performance. This was tested by growing several test crops in a number of environmentally different sites. The test crops were amaranth, taro, and cassava with amaranth receiving the greatest attention. Experimental sites were located on Oahu, Molokai, and two locations on the Big Island, Hawaii. The sites varied in temperature, moisture, and radiation regimes as well as in the chemistry and physics of the substrate. The imposed treatments were fertilizer rates and water supply. The aim of this study is to account for the expected variance in food composition and crop performance.

The effect of both controlled and uncontrolled environmental factors on the number of days required for a crop of amaranth to mature differed among sites, and in some instances between treatments within sites. It will become increasingly evident in this study that environmental factors other than those considered in this study contributed to variances in the dependent variables. In the absence of insects, weeds, and pathogens, water, nutrients, and energy supply are expected to affect crop performance. If water, nutrients, and pests are controlled, energy supply in heat units becomes the major contributor to differences in growth and development. Photoperiod can also affect crop performance, but in the amaranth experiment, all plantings were completed within a two week period and the small latitudinal difference between Oahu and the Big Island of Hawaii was not expected to affect daylength.

This chapter is written in two parts. The first deals with the effect of controlled and uncontrolled environmental factors on crop growth, development, and performance of crops with emphasis on amaranth, and the second with the effect of environmental factors on the nutrient and antinutrient content of the same crops.

4.1 Growth and development of amaranth

In evaluating the effects of controlled and uncontrolled environmental factors on amaranth, three crop-related parameters are considered which include (1) number of heat units required by amaranth to develop from planting to harvesting, (2) dry weight of amaranth, and (3) moisture content of amaranth.

4.1.1 Energy utilized by amaranth for emergence and growth

All things being equal, the heat units required by plants of the same genotype to develop to a particular phenological stage should be the same. In order to obtain information about the temperature requirement of amaranth in this study, heat units in degree days[1] were computed

[1] Heat unit (degree days):

$$\text{Heat unit/day} = \frac{T_{max} + T_{min}}{2} - T_{base}$$

for the period between planting and harvest of the plants (Table 4.1). With the exception of the Iole, irrigated and Waipio, non-irrigated, the number of heat units required by the plants to reach harvest age after planting ranged from 581 to 769 degree days (Table 4.1). The higher cumulative heat units exhibited by Iole, irrigated plants are likely due to the uneven emergence and the late harvest of these plants. The higher cumulative heat units exhibited by Waipio, non-irrigated plants are due to the delayed and uneven emergence resulting from lack of moisture.

Disregarding the Waipio, non-irrigated and the Iole, irrigated treatments for the reason stated above, Iole plants took the longest chronological time to reach harvest age. But in terms of heat units, or thermal time, the Iole plants required nearly identical heat units to reach harvest age as did plants from Waipio. This suggests that amaranth requires the same number of heat units to reach a particular phenological stage. Because Iole occurs in a cooler environment, it takes longer to accumulate the same amount of heat units. According to a National Research Council report (1984), optimal germination temperatures of various accessions of amaranth varied between 16-35^{o}C. The speed of seed emergence was increased at the upper end of this range. Iole had the lowest minimum temperature of 13^{o}C (Table 3.20).

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where T_{max} = Maximum daily air temperature
T_{min} = Minimum daily air temperature
T_{base} = The lowest temperature whereby the metabolic functions and growth of plants ceases. The temperature of 10^{o}C was used for amaranth.
Heat unit for a period of plant development is the sum of heat units/day over that period.

Table 4.1

Number of days and heat unit (degree days) from date of planting to harvest in the amaranth experiments

Growth duration	Treatment*	Site					
		Iole		Kukaiau		Waipio	
		Days	Degree days	Days	Degree days	Days	Degree days
Planting	NI	95	769	71	581	161	1942
to harvest	I	150	1255	71	581	70	757

* NI = Non-irrigated treatment; I = Irrigated treatment.

The lower degree days recorded for the Kukaiau site can be attributed to the early harvest date. Although every attempt was made to harvest each crop just before flowering, it was not possible to forecast flowering and to be on each island to await the proper harvest date.

The fact that it took approximately 25 additional days in Iole, non-irrigated treatment to accumulate the same number of heat units as in Waipio clearly indicates that the agroenvironments are different. This difference is essential to test the hypothesis that nutrient contents of cultivar depends on the agroenvironment in which it is grown.

4.1.2 Dry weight

Based on the concept of equal energy utilized by plants of the same genotype to develop to the same phenological stage, the dry weight comparisons are made on those that exhibited equal energy utilization (Table 4.1). These include the dry weight comparison between Iole, non-irrigated plants and Waipio, irrigated plants; and the comparison between Kukaiau, non-irrigated and irrigated plants.

Table 4.2 shows that the plant dry weights from non-irrigated plots of Iole (90.5 g) and irrigated plots of Waipio (29.5 g) were significantly different. This difference may be attributed almost totally to the difference in agroenvironment. The moisture contents of these two groups of plants were similar as shown in Table 4.5 and, indicate that irrigation in Waipio compensated for natural rainfall in Iole. As shown in Tables 4.24 and 4.25, total N concentration and uptake in Iole, non-irrigated plants were significantly higher than those from Waipio, irrigated plants. This was likely because there was more N in the Iole soil than in that of Waipio soil (Table 3.17). This should be the main reason for higher dry weight in Iole.

Higher dry weight from the non-irrigated than irrigated plants (Table 4.2) was also found by Varde (1984) for soybean and cabbage grown in Kukaiau. Tables 4.23 and 4.25 show that uptake of cations, anions and N was higher in plants from the non-irrigated plots than the irrigated ones.

Phosphate fertilizer increased yields significantly in both non-irrigated and irrigated plants in Kukaiau and apparently also increased yields of non-irrigated plants at Iole (Table 4.3). These results confirm the notion that P is a limiting nutrient in Hydric Dystrandepts. Application of N fertilizer increased the dry weight of Waipio, irrigated plants significantly (Table 4.3). This shows that N was a major limiting nutrient in the Tropeptic Eutrustox. The Benchmark Soils

Table 4.2

Effect of irrigation treatment on dry weight of amaranth

Treatment	Site		
	Kukaiau	Iole	Waipio
		(g/10 plants)	
Non-irrigated	65.3	90.5[a]	31.0
Irrigated	37.3	124.6	29.5[a]
Significance level (F-test)	0.0871	0.6864	0.8151

[a]The two means are significantly different at 0.05 probability level according to the least squares comparison.

Project (1979) also demonstrated that P deficiency was frequently encountered in Hydric Dystrandepts, while N was deficient in most cultivated Eutrustox due to its susceptability to leaching.

Dry weight was not affected significantly by irrigation (Table 4.2) but the irrigation x fertilizer interaction was significant in Waipio plants (Appendix A). Significantly higher dry weight was found in N-treated Waipio, irrigated plants than in the N-treated, non-irrigated, Waipio plants (Table 4.3, Figure 4.1). N and uptake of other nutrients in Waipio plants also showed this significant irrigation x fertilizer effects (Appendix A, Table 4.12). This indicates that providing adequate water is essential for proper growth and nutrient uptake in a dry site like Waipio.

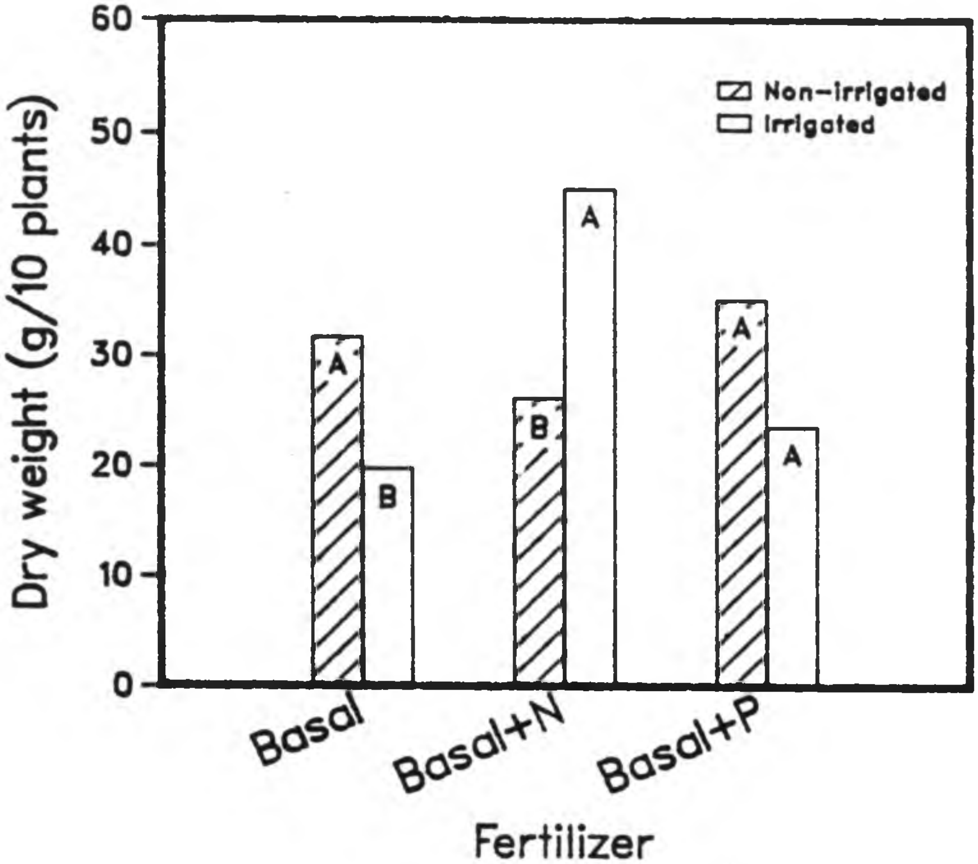
Table 4.3

Effects of fertilizer N and P on dry weights of amaranth in irrigated and non-irrigated plots at three sites

Fertilizer	Dry weight (g/10 plants)					
	Kukaiau		Iole		Waipio	
treatment	NI[a]	I[a]	NI[a]	I[a]	NI[a]	I[a]
Basal	35.4 Ba[b]	20.6 Ba[b]	67.5 Aa[b]	151.2 Aa[b]	31.7 Ab[b]	19.8 Ba[b]
Basal+N	46.1 Ba	23.1 ABa	59.9 Aa	165.3 Aa	26.2 Ab	45.1 Aa
Basal+P	114.5 Aa	68.2 Aa	144.0 Aa	70.9 Aa	35.1 Aa	23.6 Ba

[a]NI = Non-irrigated, I = Irrigated

[b]Means within the same location and irrigation treatment followed by the same capital letter are not significantly different at the 0.05 probability level. Means within the same location and fertilizer treatment followed by the same small letter are not significantly different at 0.05 probability level according to the least squares pair comparison.



Means of the same fertilizer treatment with the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

Figure 4.1 Effect of irrigation x fertilizer interaction on dry weight of amaranth grown at Waipio site.

4.1.3 Moisture content of plant tissue

The higher rainfall in Kukaiau and Iole led to significantly higher tissue moisture contents than those from Waipio (Table 4.4). Table 4.5 shows that in the Kukaiau and Iole sites irrigation did not increase tissue moisture content. In Iole, however, the non-irrigated plants had significantly higher tissue moisture content than the irrigated plants. These observations are not unexpected as Iole and Kukaiau receive sufficient rainfall during much of the year, and irrigation may not be required or in some cases may depress plant growth through excess water. If irrigation is to have sufficient beneficial effects, it would do so in Waipio where rainfall is infrequent. The non-irrigated Waipio plants displayed their response to water stress by their small leaves and large proportion of stems (Table 3.3).

Table 4.4

Tissue moisture contents of amaranth grown at different sites

Site	Moisture content* (% fresh weight)
Kukaiau	89.7 A
Iole	87.1 B
Waipio	85.7 C

*Means followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

Table 4.5

Moisture content of amaranth grown at three different sites as affected by irrigation treatments

Site	Treatment[a]	Tissue moisture content (% fresh weight)
Kukaiau	NI	89.6
	I	89.9
Significance level (F-test)		0.6185
Iole	NI	88.9
	I	85.0
Significance level (F-test)		0.0014
Waipio	NI	81.4
	I	90.1
Significance level (F-test)		0.0001

[a]NI = Non-irrigated, I = Irrigated

4.2 Oxalate composition of amaranth tissue

4.2.1 Forms and amount of oxalate in amaranth

Two dominant fractions were found in amaranth. These were the water soluble and water insoluble fractions. Free oxalic acid (alcohol soluble fraction) could not be detected by the methods used in this study.

In an attempt to identify the accompanying cation in each oxalate fraction, correlations between the oxalate concentration of each fraction with its cations and with the cations in the plant tissue were determined (Table 4.6, Figures 4.2-4.5).

The high correlation between the concentrations of tissue K and K in the soluble oxalate fraction with the soluble oxalate, r=0.6392 and 0.6403, respectively (Table 4.6, Figure 4.2), suggested that K oxalate was the main form of soluble oxalate. However, the higher correlation between the concentration of K plus Mg in the soluble oxalate fraction with the soluble oxalate, r=0.8558, suggested that Mg oxalate was an important part of the soluble oxalate (Figure 4.3).

Considering the insoluble oxalate fraction, the high and significant correlation between the concentrations of tissue Ca and Ca in the insoluble oxalate fraction with that of the insoluble oxalate (Table 4.6, Figure 4.4) shows that Ca oxalate was the main form of this fraction. However, the improved correlation with Ca plus Mg was substituted for Ca (Figure 4.5) suggested that Mg oxalate was also an important constituent of the insoluble oxalate fraction. In addition, a portion of the Mg oxalate was probably extracted by hot water.

Table 4.6

Correlation between soluble and insoluble fractions of oxalate with mineral composition of plant tissue and of fractionation extracts of amaranth

Mineral composition of tissue and fractions	Correlation coefficient* (Probability > |r|) Soluble fraction of oxalate	 Insoluble fraction of oxalate
Tissue K	0.6392 (0.0001)	-0.2146 (0.1346)
" Ca	-0.3869 (0.0055)	0.6043 (0.0001)
" Mg	-0.0436 (0.7639)	-0.1528 (0.2896)
" Na	-0.0090 (0.9505)	-0.2031 (0.1571)
Soluble fraction K	0.6403 (0.0001)	-0.3465 (0.0128)
" " Ca	-0.1689 (0.2360)	-0.1112 (0.4371)
" " Mg	0.4087 (0.0029)	-0.3549 (0.0126)
" " Na	0.0287 (0.8413)	-0.2538 (0.0723)
" " K + Mg	0.8558 (0.0001)	-0.5493 (0.0001)
Insoluble fraction K	-0.3240 (0.0204)	0.6980 (0.0001)
" " Ca	-0.3417 (0.0141)	0.6541 (0.0001)
" " Mg	-0.0930 (0.5161)	0.5227 (0.0001)
" " Na	-0.1702 (0.2325)	0.3849 (0.0053)
" " Ca + Mg	-0.3349 (0.0163)	0.7410 (0.0001)

*Number of observations = 54

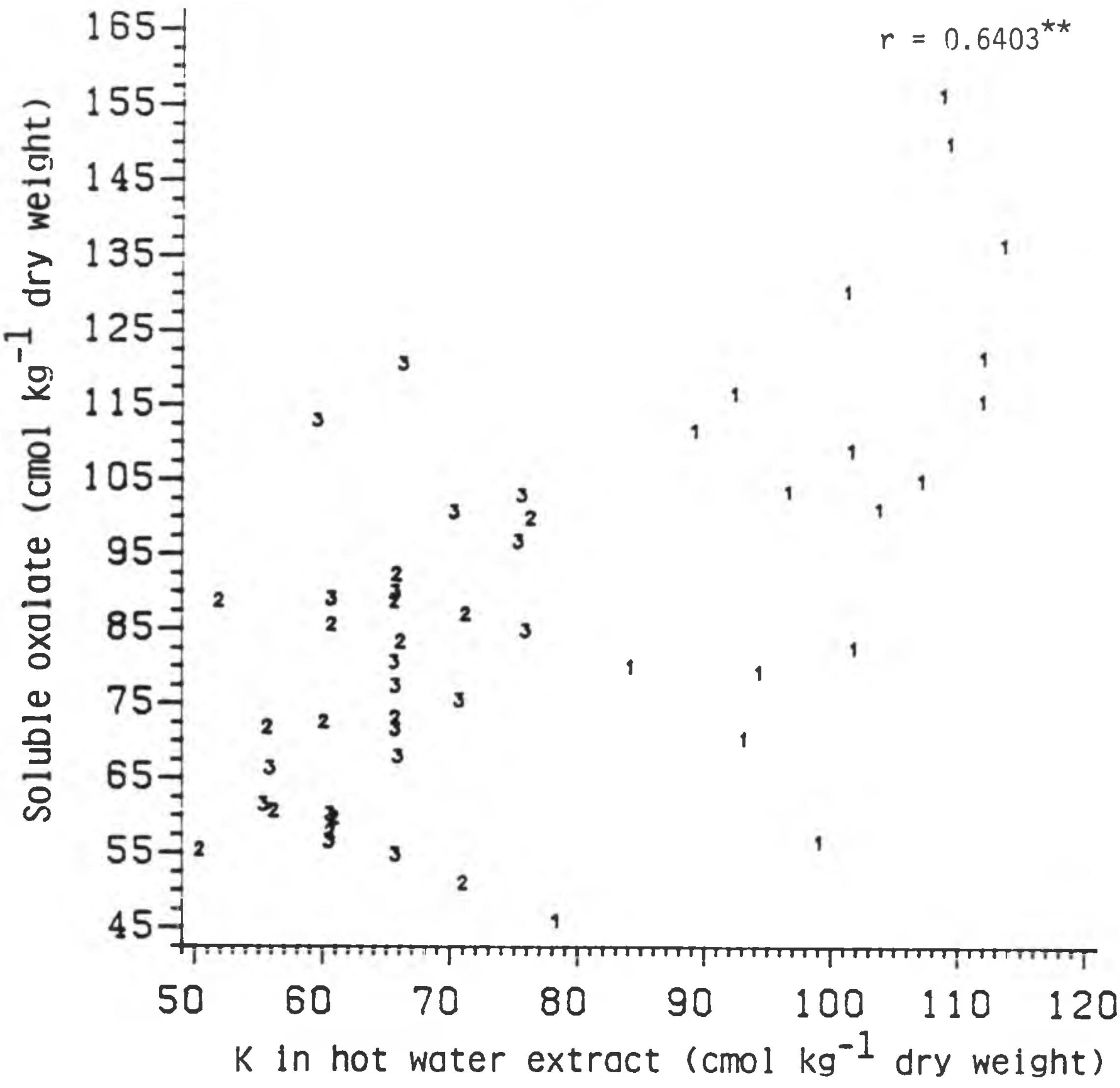


Figure 4.2. Relationship between soluble oxalate and K concentration in the extract of soluble oxalate fraction (hot water extract) of amaranth tissue (1=Kukaiau, 2=Iole, 3=Waipio).

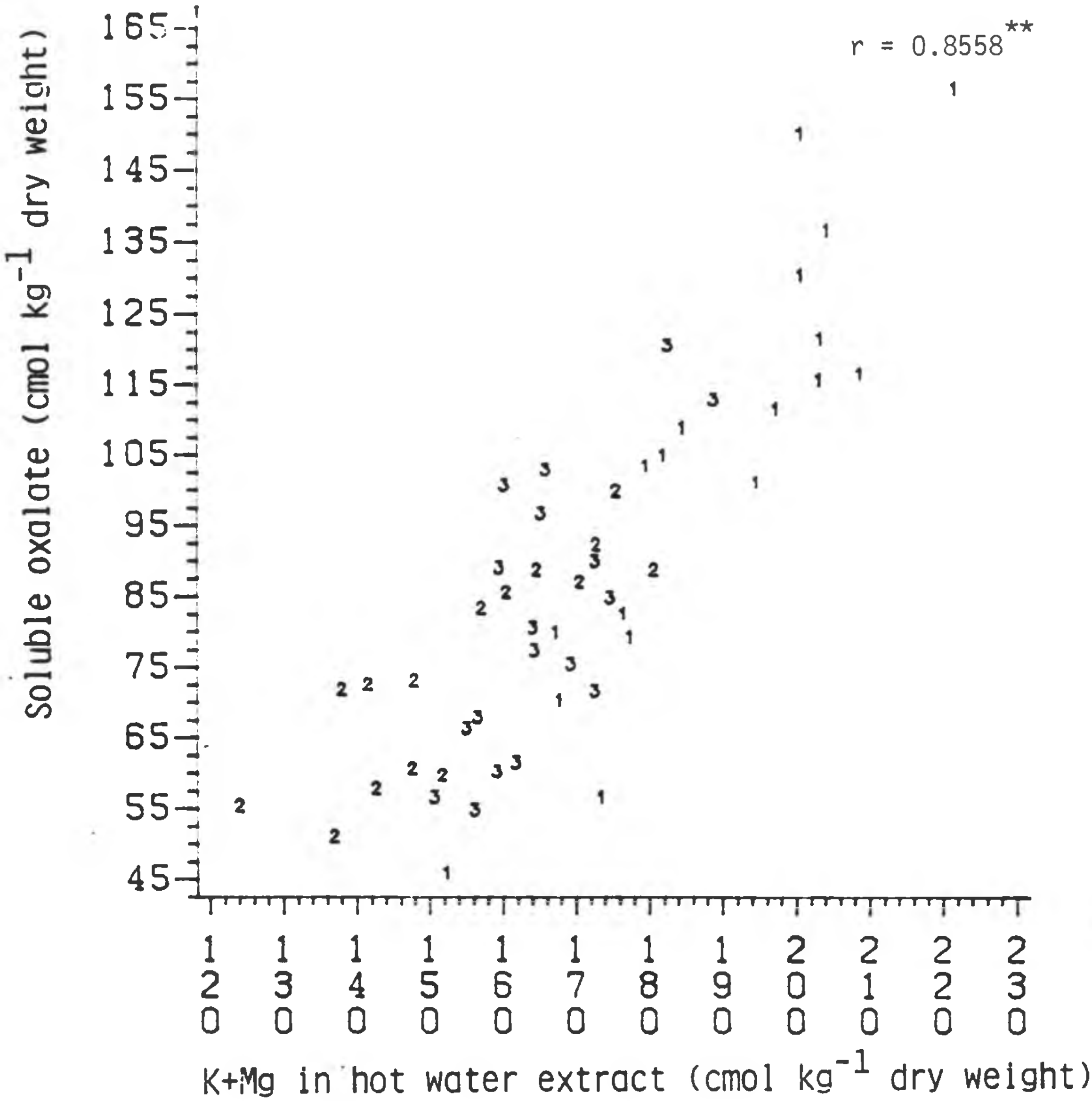


Figure 4.3 Relationship between soluble oxalate and the sum of potassium and magnesium concentration in the extract of soluble oxalate fraction (hot water extract) of amaranth tissue
(1=Kukaiau, 2=Iole, 3=Waipio).

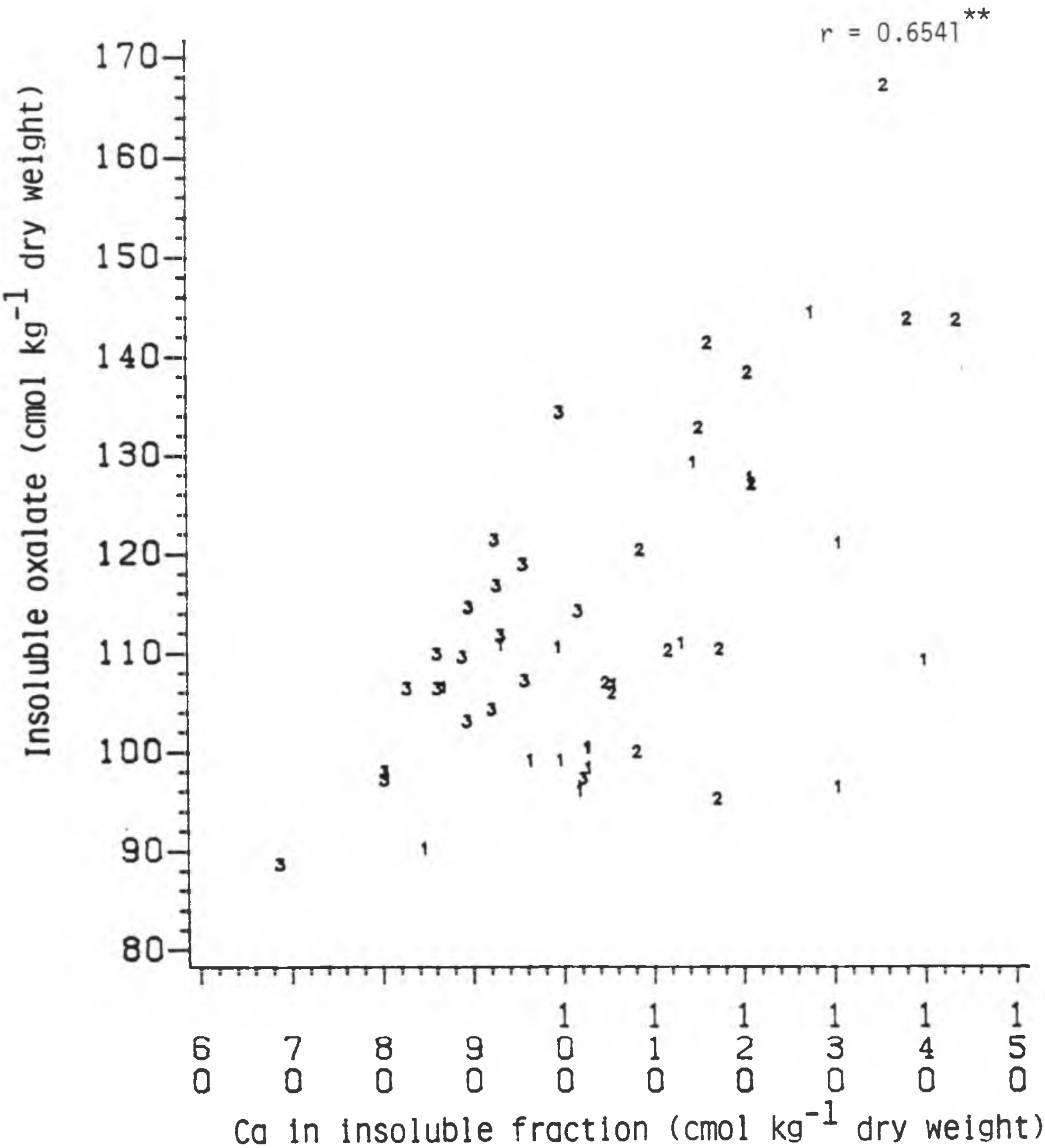


Figure 4.4 Relationship between insoluble oxalate and Ca concentration in the extract of insoluble oxalate fraction of amaranth tissue (1=Kukaiau, 2=Iole, 3=Waipio).

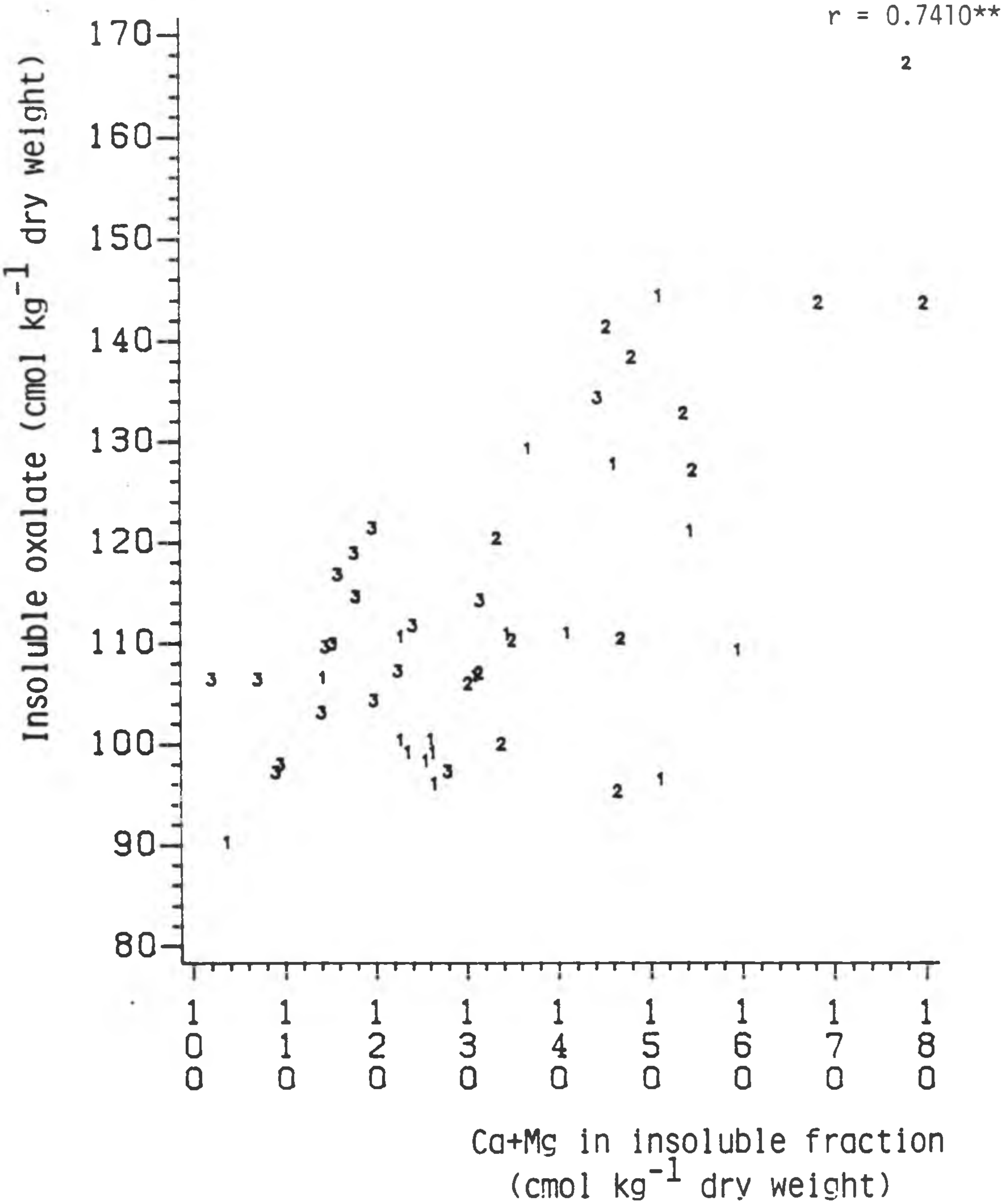


Figure 4.5 Relationship between insoluble oxalate and the sum of Ca and Mg concentration in the extract of insoluble oxalate fraction of amaranth tissue (1=Kukaiau, 2=Iole, 3=Waipio).

The analysis of cations, including Ca, Mg, K and Na, in the soluble and insoluble fractions showed that the dominant cations in the soluble and insoluble fractions were respectively K and Ca (Table 4.7). There was relatively little K in the insoluble fraction extract and little Ca in the soluble fraction extract (Table 4.7). In Table 4.7, the sum of the cations must be greater than the oxalate concentration because other organic and inorganic anions were present in the extract.

The concentration of soluble oxalate in plants from all three sites were nearly the same as that of K. It is likely that the remainder of soluble oxalate was in the forms of Mg oxalate and Na oxalate. The small amount of Ca found in this fraction was probably associated with water soluble salts, such as $CaCl_2$ (Table 4.7a).

Considering the insoluble fraction (Table 4.7b), the high Ca concentration which almost matched the concentration of insoluble oxalate was strong evidence that Ca oxalate was the dominant form in the insoluble fraction. The remaining insoluble oxalate should be in the form of Mg oxalate. The correlation between Mg in the insoluble fraction and insoluble oxalate was significant (Table 4.6).

Total oxalate in amaranth grown in Kukaiau was more than 9%. It is interesting to note that higher concentrations of insoluble oxalate were found in amaranth grown in all sites (Table 4.8). Plants from Iole had 27% more insoluble oxalate than soluble oxalate, while Waipio plants had 14% and Kukaiau plants had 2% more.

Two values of 'total oxalate' were obtained in this study. One was measured directly and the other was computed by adding the two

Table 4.7

Mineral concentrations in the (a) soluble, and (b) insoluble fractions of oxalate in amaranth from all plots in three sites

(a)

Site	Minerals and oxalate concentration (cmol kg^{-1} dry weight)						
	Oxalate	Ca	Mg	K	Na	SC*	Total cation - total oxalate
Kukaiau	104.0	0.9	88.6	100.0	4.6	194.1	90.1
Iole	75.2	0.8	91.6	62.5	3.7	158.6	83.4
Waipio	81.6	1.0	99.9	65.6	9.9	176.4	94.8

(b)

Site	Minerals and oxalate concentration (cmol kg^{-1} dry weight)						
	Oxalate	Ca	Mg	K	Na	SC*	Total cation - total oxalate
Kukaiau	108.7	108.5	24.7	2.3	1.4	136.9	28.2
Iole	128.2	120.4	30.5	3.4	1.4	155.7	27.5
Waipio	108.8	89.8	27.3	1.4	1.3	119.8	11.0

* Sum of cation concentration

Table 4.8

Relative concentrations of different fractions of oxalate produced in amaranth grown at three sites

Site	% dry weight				%	
	Total	Soluble+ insoluble	Soluble	Insoluble	Soluble	Insoluble
Kukaiau	9.2	4.7	9.6	4.9	49	51
Iole	8.4	9.2	3.4	5.8	37	63
Waipio	7.5	8.6	3.7	4.9	43	57

oxalate fractions. Since the two values were significantly different (Table 4.9), the sum of the two fractions was used to obtain percent of any fraction relative to total oxalate.

Table 4.9

Comparison of the two means of total oxalate of amaranth obtained by two different methods

Mean of total oxalate	Mean of soluble+insoluble oxalate
(cmol kg^{-1} dry weight)	
185.8	201.7

t-test = -2.9894

Probability > |t| = 0.0035

4.2.2 Oxalate and calcium concentrations in amaranth tissue

Figure 4.6 shows that the concentrations of insoluble oxalate and tissue Ca were very close. This indicates that most Ca in amaranth tissue was bound in the form of Ca oxalate and was not available as a nutrient.

4.2.3 Comparison of chemical composition in plants grown at different sites

Concentrations and productions of total, soluble, insoluble and the combination of the soluble and insoluble oxalate were significantly different among the sites (Tables 4.10 and 4.11). Plants from Kukaiau had more total and soluble oxalate than those from Iole and Waipio. On the other hand, plants in Iole had higher insoluble oxalate concentration than Kukaiau and Waipio plants (Table 4.10). Iole plants produced significantly higher quantities of all forms of oxalate than Kukaiau or Waipio plants (Table 4.11).

Table 4.10

Oxalate concentrations in amaranth grown at three sites

Site	Oxalate concentrations (cmol kg^{-1} dry weight)			
	Total*	Soluble*	Insoluble*	Soluble + insoluble*
Kukaiau	204.3 A	104.0 A	108.7 B	212.7 A
Iole	186.9 B	75.2 B	128.2 A	203.4 A
Waipio	166.3 C	81.6 B	108.8 B	190.4 B

* Means in the same column followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

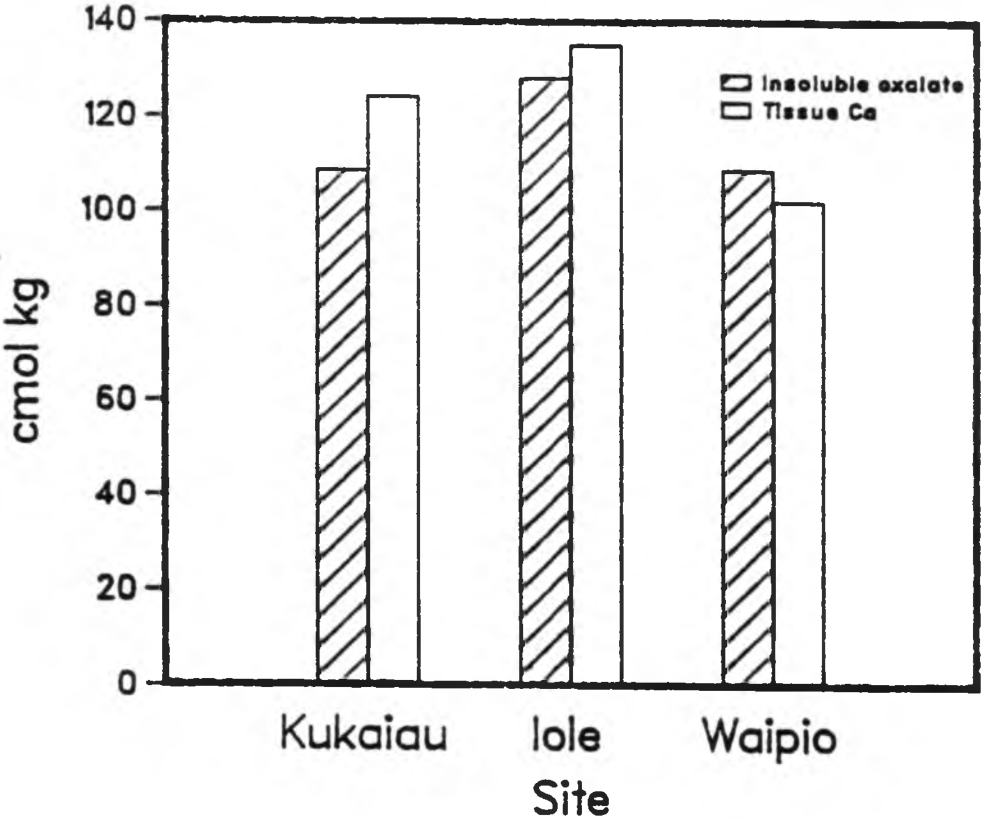


Figure 4.6. Comparative concentration of insoluble oxalate and tissue Ca in amaranth growth at three sites.

Table 4.11

Oxalate production in amaranth grown at three different sites

Site	Oxalate production (g/10 plants)			
	Total*	Soluble*	Insoluble*	Soluble + insoluble*
Kukaiau	4.6 B	2.0 B	2.7 B	4.7 B
Iole	9.8 A	3.7 A	7.0 A	10.8 A
Waipio	2.3 B	1.1 B	1.5 B	2.6 B

*Means in the same column followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

Ionic and total N concentrations in plant tissue are thought to be factors affecting the oxalate concentrations in plants. Kukaiau and Iole plants had higher tissue ionic concentrations and uptake values than Waipio plants (Tables 4.12 and 4.13). They also had higher total N concentration and uptake than Waipio plants (Tables 4.18 and 4.19). Schmidt et al. (1971) reported that Amaranth species which were grown on soils with high soil carbon, nitrogen, available phosphorus and potassium contents produced higher total oxalate relative to those grown on less fertile soils. Although the Kukaiau and Iole soils were less fertile than the Waipio soil with respect to base status, they had higher nitrogen contents than the Waipio soil. Consequently, plants from Kukaiau and Iole had higher concentrations and uptake of various ions than those from Waipio. More importantly, Kukaiau and Iole plants had higher cation excess than Waipio plants (Table 4.12). According

Table 4.12

Ionic concentrations and cation excess contents of amaranth grown at three sites

Site	Ca	Mg	K	Na	SC**	P	S	NO_3	Cl	SA***	C-A
	----------	----------	----------	----------	cmol kg^{-1}	dry weight	----------	----------	----------	----------	----------
Kukaiau	124.4 B*	99.3 C*	147.6 A*	5.0 B*	376.1 A*	3.4 A*	8.3 C*	31.1 A*	7.1 B*	49.9	326.3 A*
	(2.49)	(1.19)	(5.77)	(.11)		(.33)	(.40)	(1.92)	(.25)		
Iole	135.1 A	118.4 A	117.9 B	4.9 B	376.3 A	2.6 B	10.1 A	23.4 B	6.9 B	43.0	333.3 A
	(2.70)	(1.42)	(4.61)	(.11)		(.25)	(.49)	(1.45)	(.24)		
Waipio	102.2 C	112.4 B	108.2 C	8.5 A	331.4 B	3.1 A	9.3 B	9.6 C	7.6 A	29.6	301.7 B
	(2.04)	(1.34)	(4.23)	(.11)		(.30)	(.45)	(.60)	(.27)		

* Means in the same column followed by the same letter are not significantly different at 0.05 level of probability (Waller-Duncan's multiple range test).

** Sum of cation concentration

*** Sum of anion concentration

Table 4.13

Ionic uptake by amaranth grown at three sites

Site	Ca	Mg	K	Na	P	S	NO_3	Cl
	----------	----------	----------	g/ 10 plants	----------	----------	----------	----------
Kukaiau	1.4 B*	0.6 B*	2.9 B*	0.06 B*	0.17 B*	0.23 B*	0.95 A*	0.14 B*
Iole	3.4 A	1.5 A	5.0 A	0.10 A	0.27 A	0.53 A	1.44 A	0.27 A
Waipio	0.6 B	0.4 B	1.3 B	0.06 B	0.09 B	0.14 B	0.18 B	0.08 B

* Means in the same column followed by the same letter are not significantly different, at 0.05 level of probability (Waller-Duncan's multiple range test).

to the cation-anion balance concept, organic acids including oxalate are synthesized to balance excess cations.

The significantly higher soluble oxalate concentration in Kukaiau plants (Table 4.10) was probably due to the higher equivalent concentration of tissue K in these plants compared with Iole and Waipio plants (Table 4.12). In the previous section (4.2.1) it was concluded that soluble oxalate was primarily K oxalate.

Higher concentration and production of insoluble oxalate in plants grown in Iole relative to Kukaiau and Waipio plants (Tables 4.10, 4.11) may be attributed to the higher Ca and Mg concentrations of Iole (Table 4.12).

Soluble oxalate concentrations of Iole and Waipio plants were significantly different when only irrigated plants were considered (Table 4.14). This showed that when the variance due to irrigation effect was removed, the significant site effect emerged. The concentration of the sum of soluble and insoluble oxalate of the plants from Kukaiau and Iole were significantly different when only non-irrigated plants were considered as shown in Table 4.15.

The plants from Waipio, irrigated plots also had higher tissue K, Mg and Na but lower Ca concentration than those from Iole (Table 4.22). This was in accordance with the higher soluble oxalate in Waipio, irrigated plants than Iole plants.

It appears from these findings that the amount and distributions of the various oxalate fractions were determined to a certain extent by the type and amount of cations in amaranth tissue. In plants from Iole, Ca was the dominant cation (Table 4.12) and insoluble oxalate

Table 4.14

Soluble oxalate concentration of amaranth grown in irrigated experiments of Iole and Waipio

Site	Soluble oxalate (cmol kg^{-1} dry weight)
Iole	68.5
Waipio	85.0
Significance level (LSD)	0.0460

Table 4.15

Concentration of the sum of soluble and insoluble oxalate of amaranth grown in non-irrigated experiments of Kukaiau and Iole

Site	Soluble+insoluble oxalate (cmol kg^{-1} dry weight)
Kukaiau	212.2
Iole	191.0
Significance level (LSD)	0.0090

was the principal form of oxalate (Table 4.10). On the other hand, K was the dominant cation in Kukaiau plants (Table 4.12), but there was no significant difference between the concentrations of soluble and insoluble oxalate (Table 4.10). The Waipio plants had approximately equal concentrations of K and Ca (Table 4.12), but insoluble oxalate was the dominant form of oxalate (Table 4.10). This last result together with that from Kukaiau seemed to suggest that amaranth tended to synthesize Ca oxalate in preference to K oxalate.

Factors which affect ionic uptake by plants influence the kind and amount of oxalate produced by plants (Tables 4.10, 4.12). The plants grown in the high base, low N, Tropeptic Eutrustox did not have as high concentrations of bases in their tissue as those grown in the low base, high N Hydric Dystrandepts. This indicates that without adequate N, plants cannot make use of available resources, such as bases or phosphorus.

Tonic concentrations and uptake of plants grown at different sites

The Hydric Dystrandept in Iole appeared to be richer in Ca, Mg and K than the soil at Kukaiau (Table 3.17). This contributed to the higher concentrations of Ca and Mg in plants from Iole than in those from Kukaiau (Table 4.12). However, the significantly higher K concentration in the Kukaiau plants than in the Iole plants, in spite of the higher K concentration in the Iole soil (Table 3.17) may be due to dilution from higher biomass production in Iole.

It is likely that the significantly higher Na concentration in Waipio plants relative to Kukaiau and Iole plants was due to a high

Na concentration in the irrigation water. This was also true for Cl concentration (Table 4.12).

With the exception of Na, the higher cation and anion uptake by Kukaiau and Iole plants relative to Waipio plants (Table 4.13) was likely due to the higher biomass and plant demand of Kukaiau and Iole plants than Waipio plants. Earlier studies have shown that ion uptake is closely related to plant growth and to the supply of sugar and metabolites translocated from the shoot to the root (Pitman, 1972; White, 1973).

Relationship between oxalate concentrations and cation excess content

Total oxalate from all sites exhibited significant correlation with cation excess (Table 4.16, Figure 4.7). However, when the relationship was analyzed locationwise, only Waipio plants exhibited high and significant correlation between total oxalate and (C-A) (Table 4.16, Figure 4.8). The same situation was applicable to soluble+insoluble oxalate (Table 4.16, Figures 4.9, 4.10). Significant correlations, although not considered high, were also found between soluble oxalate and (C-A) in Waipio, and insoluble oxalate and (C-A) in Kukaiau (Table 4.16).

The results in Table 4.17 suggest that about 60% of the cation excess in amaranth grown at the three sites was balanced by oxalate.

Total N and nitrate-N concentrations and uptake and crude protein contents

Total N concentration and uptake were significantly higher in Kukaiau and Iole plants than those from Waipio (Tables 4.18 and 4.19)

Table 4.16

Correlation between concentrations of different oxalate forms and cation excess

Oxalate	Correlation coefficient (Probability > |r|)			
	Combined[a] sites	Kukaiau[b]	Iole[b]	Waipio[b]
Total	0.3916 (0.0045)	-0.3441 (0.1620)	0.3158 (0.2515)	0.6156 (0.0065)
Soluble	-0.0108 (0.9405)	-0.3697 (0.1311)	0.0940 (0.7494)	0.4815 (0.0431)
Insoluble	0.4793 (0.0004)	0.5229 (0.0206)	0.3619 (0.2036)	0.3905 (0.1091)
Soluble + insoluble	0.3442 (0.0144)	-0.1751 (0.4871)	0.4146 (0.1405)	0.5790 (0.0118)

[a]Number of observations = 54

[b]Number of observations = 18

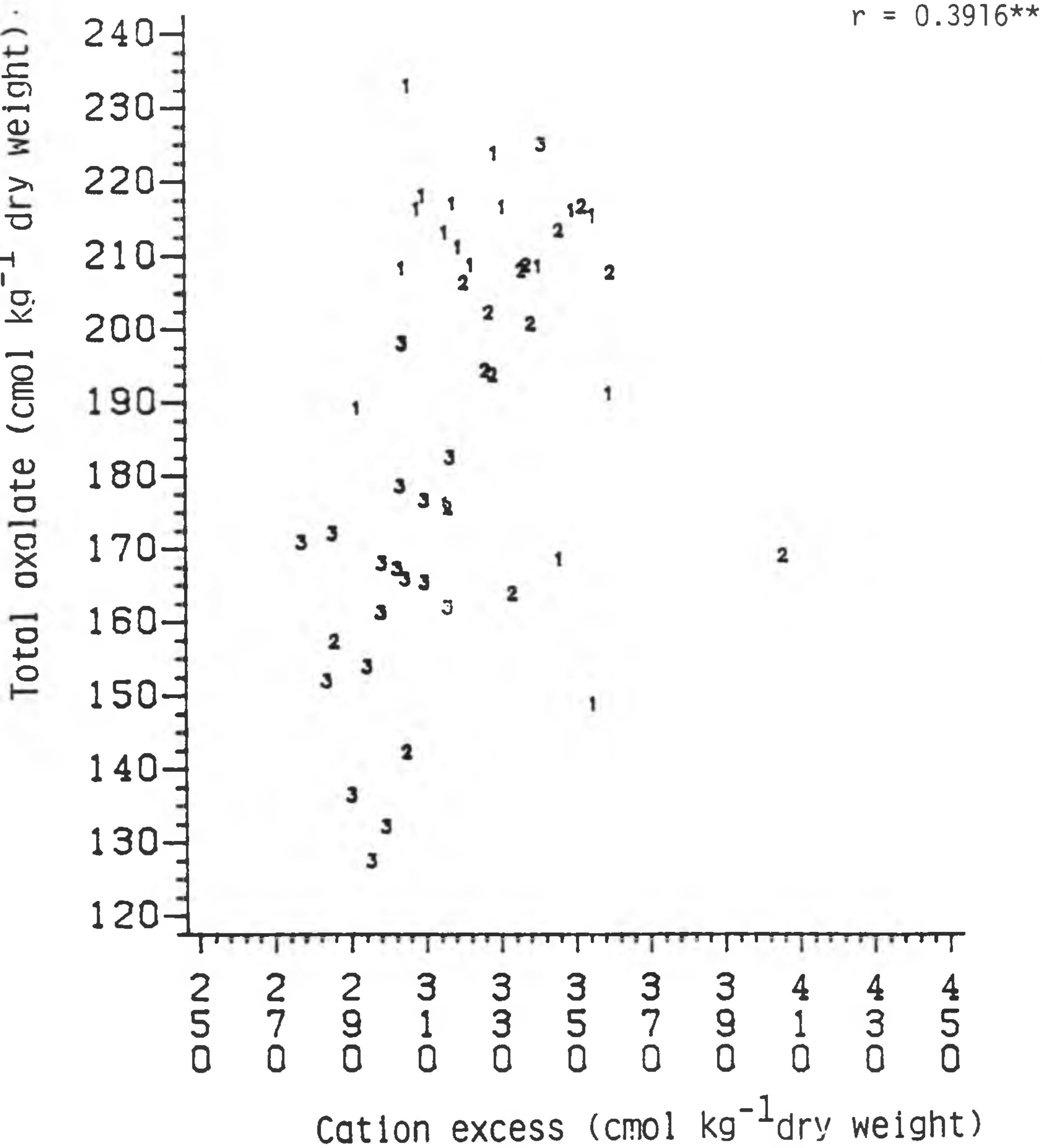


Figure 4.7. Relationship between total oxalate and cation excess in amaranth from all plots of the experiments at three sites
(1=Kukaiau, 2=Iole, 3=Waipio).

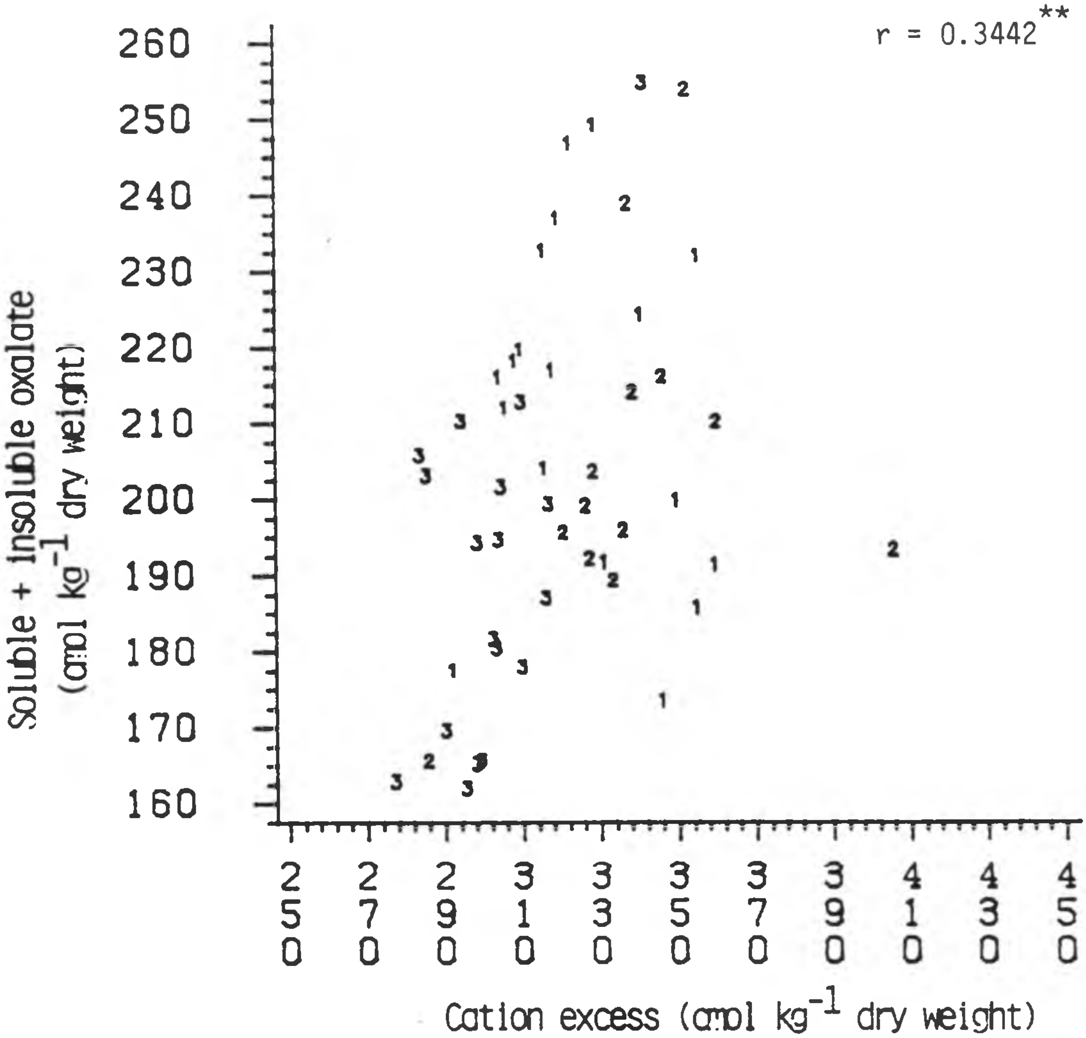


Figure 4.8. Relationship between the sum of soluble and insoluble oxalate and cation excess in amaranth from all plots of the experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

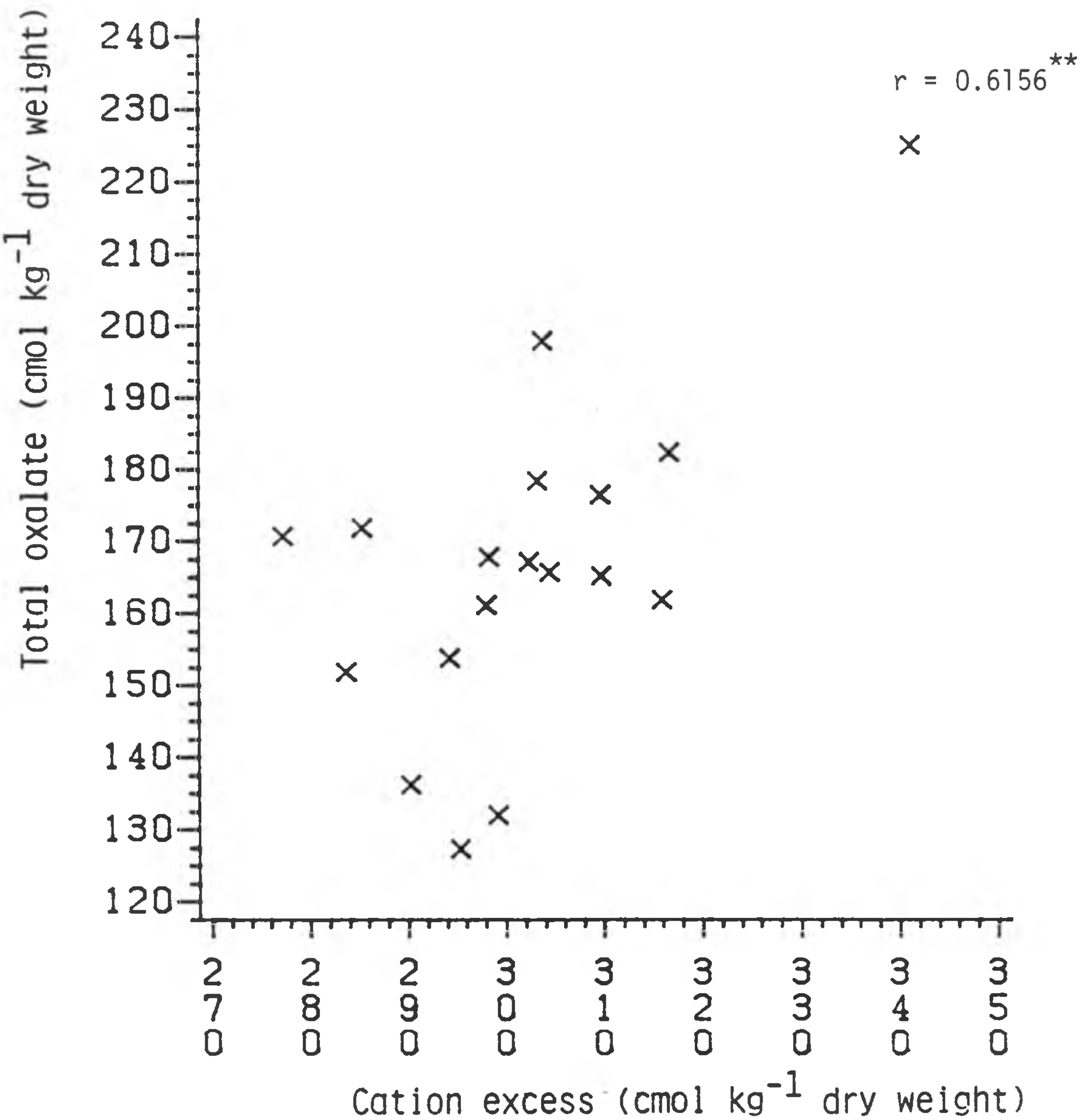


Figure 4.9. Relationship between total oxalate and cation excess in amaranth from Waipio site.

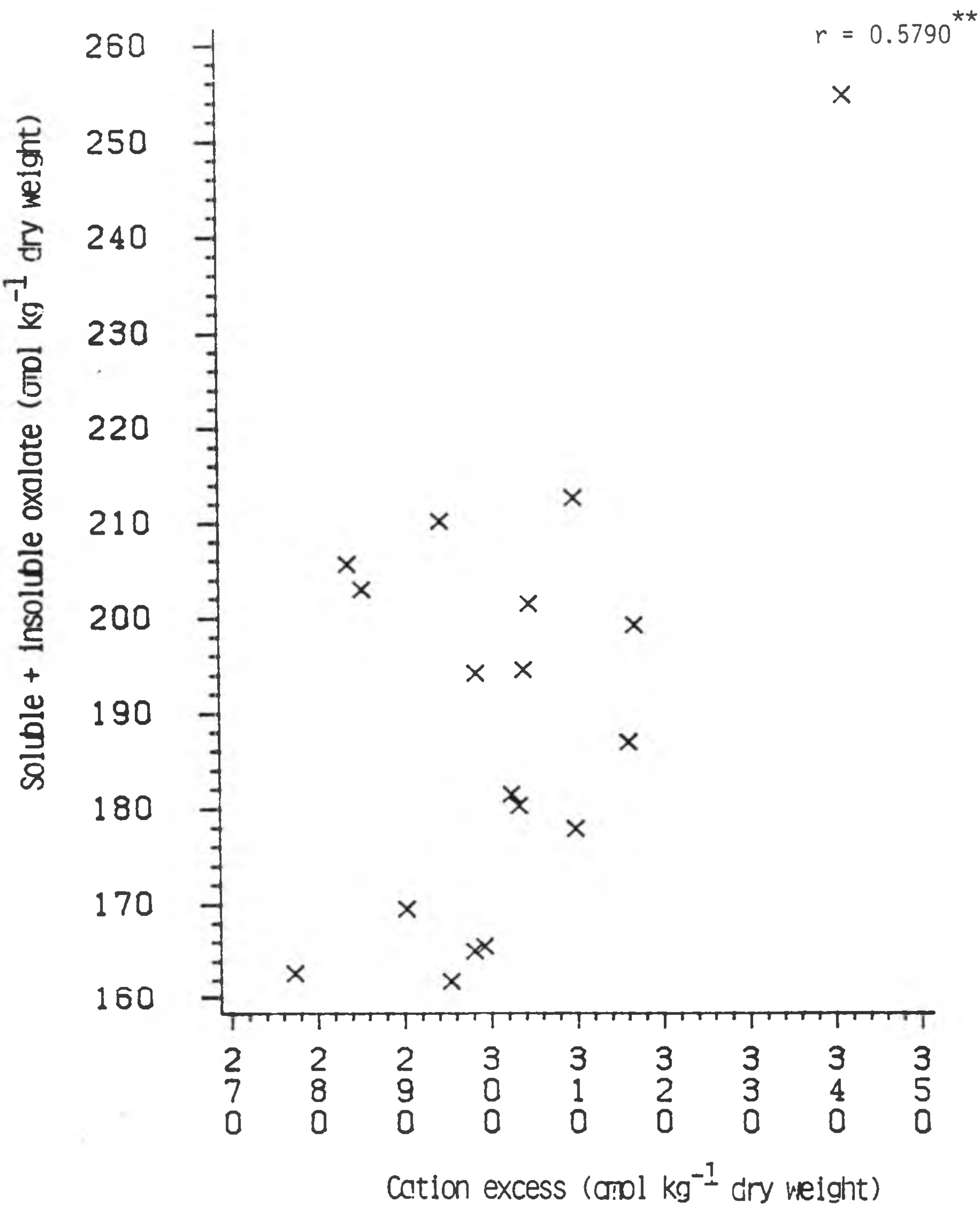


Figure 4.10. Relationship between the sum of soluble and insoluble oxalate and cation excess in amaranth from Waipio site.

Table 4.17

Proportion of total oxalate and the sum of soluble and insoluble oxalate relative to cation excess (C-A)

Site	(C-A) ($cmol\ kg^{-1}$)	Total oxalate		Soluble+insoluble oxalate	
		Conc. ($cmol\ kg^{-1}$)	% (C-A)	Conc. ($cmol\ kg^{-1}$)	% (C-A)
Kukaiau	326.3	204.3	62.6	212.7	65.2
Iole	333.3	186.9	56.1	203.4	61.0
Waipio	301.7	166.3	55.1	190.4	63.1

Table 4.18

Total N, nitrate-N concentration and crude protein content of amaranth grown at three sites

Site	Total N*	Nitrate-N*	Crude protein*
	% dry weight		
Kukaiau	4.53 A	0.52 A	28.3 A
Iole	4.28 B	0.33 B	26.8 B
Waipio	3.28 C	0.13 C	20.5 C

* Means in the same column followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

Table 4.19

Total N and nitrate-N uptake by amaranth grown at three sites

Site	Total N*	Nitrate-N*
	------------ g/10 plants -----------	
Iole	4.77 A	1.44 A
Kukaiau	2.24 B	0.95 A
Waipio	0.99 B	0.18 B

* Means in the same column followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

and this is related to soil nitrogen levels. When the tissue total N values were converted to crude protein (on a dry weight basis), they were comparable to the values of 27-33% reported by the National Research Council (1984) for four species of amaranth. However, the crude protein of Waipio plants was lower relfecting the low N content of the Tropeptic Eutrustox.

The higher total N uptake in Kukaiau and Iole plants (Table 4.19) reflected larger biomass production at Kukaiau and Iole. Even though the Waipio plants, especially the irrigated ones, had the advantage of higher solar radiation and temperature relative to Kukaiau and Iole plants, low N prevented higher yields from being achieved in Waipio. When soil N is deficient growth rate is low, and plant nutrient demand is also low, consequently, the uptake of other nutrients becomes low also, although they are available. White (1973) has pointed out that P uptake depends on the relative growth rate and on environmental factors, including the supply of other essential nutrients, such as nitrogen.

The nitrate-N content of amaranth grown in Kukaiau and Iole (Table 4.18) were comparable to the content of nitrate-N in various varieties of Amaranthus gangeticus L. (0.3-0.9% on a dry weight basis) reported by Der Marderosian et al. (1981). However, the nitrate-N content in Waipio plants was unusually low, only 0.13% (Table 4.18). This is additional evidence that the N content of the Waipio soil was too low to support the normal growth of plants. Nitrate accumulation is regarded as a natural and necessary process in plants and attempts to reduce nitrate accumulation can result in yield reduction (Lorenz, 1978).

Whether nitrate concentration found in amaranth in this study was potentially toxic depends on the amount of fresh vegetable consumed. Given a moisture content of 90% and a nitrate-N content on a dry weight basis of 0.5% (e.g., the content in amaranth grown in Kukaiau, Table 4.18), the nitrate-N on a fresh weight basis would be 0.05%. According to Gilbert et al. (1946) 0.5 g is a toxic daily dose. Thus, approximately 1000 g of fresh amaranth would need to be consumed each day to attain toxic levels of nitrate-N intake. Der Marderosian et al. (1981) did not think that more than 100 g fresh green vegetables would be consumed in a day. Their argument was probably based on an American diet. The recommended quantity of vegetable diets for various groups of people in Africa is 150 g (Latham, 1979). Therefore, it appears that the nitrate-N content in amaranth will not be a health hazard unless an unlikely large quantity of this vegetable is consumed fresh.

When green vegetables are cooked, especially by boiling or blanching, a large part of nitrate is dissolved in cooking water. Vegetables prepared this way will have less nitrate-N content, and less potential health hazard.

4.2.4 Effect of irrigation on plant chemical composition

The uneven performance of amaranth did not permit the effect of irrigation to be interpreted clearly. As pointed out in Chapter III the irrigated plots at each experimental site were treated as if irrigation was the main plot of a split-plot design when in fact, it was not. Thus, the irrigation effect should be interpreted with this in mind. In addition, the Kukaiau and Iole sites are naturally wet and, consequently, irrigation would not necessarily result in different plant performance. This is reflected in moisture contents of amaranth from Kukaiau and Iole as shown in Table 4.5.

On the other hand, Waipio is a dry site and, hence, the irrigation effect was anticipated to be greater. However, the effect of irrigation there was confounded by the fact that the non-irrigated and irrigated crops were harvested at different times which resulted in their being exposed to different weather. This was also true for the Iole, non-irrigated and irrigated plants where the irrigated crop was left in the field for a much longer period.

The significantly higher insoluble oxalate content in Iole, irrigated amaranth relative to the non-irrigated treatment as shown in Table 4.20 went hand in hand with the higher Ca concentration in the amaranth from the irrigated plots (Table 4.22). This difference

Table 4.20

Effect of irrigation on oxalate concentration of amaranth grown at three sites

Oxalate	Irrigation treatment	(cmol kg^{-1} dry weight) Kukaiau	Iole	Waipio
Total	non-irrigated	201.3	190.5	169.0
	Irrigated	207.4	182.2	163.6
Significance level (F-test)		0.5889	0.4755	0.4722
Soluble	Non-irrigated	99.0	78.4	78.2
	Irrigated	108.9	70.4	85.0
Significance level (F-test)		0.4009	0.3383	0.5060
Insoluble	Non-irrigated	113.2	112.7	110.4
	Irrigated	104.2	151.6	107.2
Significance level (F-test)		0.0727	0.0235	0.5155
Soluble+Insoluble	Non-irrigated	212.2	191.0	188.6
	Irrigated	213.1	221.9	192.2
Significance level (F-test)		0.9379	0.2476	0.7107

in insoluble oxalate content was most likely due to the difference in age and harvest time.

The higher concentration of soluble oxalate in irrigated than the non-irrigated amaranth from Kukaiau (Table 4.20) appears to be associated with the higher K concentration in the irrigated plants (Table 4.22). On the other hand, soluble oxalate production and K uptake were lower in the irrigated Kukaiau plants than in the non-irrigated ones (Tables 4.21, 4.23). This suggests that the lower concentration of soluble oxalate in the non-irrigated amaranth relative to the irrigated ones was primarily due to dilution from high dry matter yield (Table 4.2).

Significant differences in Ca and P contents of plants from the irrigated and non-irrigated plots were observed (Table 4.22). These differences may be the consequence of factors other than the irrigation treatment. The significantly higher Ca concentration in irrigated Iole plants, and non-irrigated Waipio plants than their counterparts may be simply due to lower Ca in the counterpart soil (Table 3.17). The same argument can be applied to the higher P content in irrigated Waipio plants than the non-irrigated ones (Table 4.22).

Significantly higher Na and Cl concentrations in Waipio irrigated plants relative to the non-irrigated ones was probably due to the high Na and Cl in the irrigation water.

Irrigation had significant effects on total N and nitrate-N concentrations only in Iole plants (Table 4.24). There are reasons to believe that this difference is not due to irrigation. It should be recalled that the irrigated plants in Iole emerged unevenly and at a

Table 4.21

Effects of irrigation on the production of oxalates in amaranth grown at three sites

Oxalate	Irrigation treatment	g/10 plants		
		Kukaiau	Iole	Waipio
Total	Non-irrigated	5.7	7.6[a]	2.4
	Irrigated	3.5	12.6	2.2[a]
Significance level (F-test)		0.1402	0.3417	0.7688
Soluble	Non-irrigated	2.5	3.0[b]	1.09
	Irrigated	1.6	4.9	1.13[b]
Significance level (F-test)		0.1373	0.5850	0.8228
Insoluble	Non-irrigated	3.6	4.6[c]	1.54
	Irrigated	1.8	10.7	1.48[c]
Significance level (F-test)		0.0536	0.3996	0.8401
Soluble + insoluble	Non-irrigated	6.0	7.6[d]	2.63
	Irrigated	3.4	15.5	2.61[d]
Significant level (F-test)		0.0764	0.4506	0.9652

a The two means are significantly different at 0.0436 probability level (LSD test).

b, c, d The two means are significantly different at 0.01 probability level (LSD test).

Table 4.22

Effect of irrigation on ionic concentration of amaranth grown at three sites

Site	Irri- gation*	cmol kg^{-1} dry weight (% dry weight)							
		Ca	Mg	K	Na	P	S	NO_3	Cl
Kukaiau	NI	125.9 (2.59)	101.3 (1.22)	144.5 (5.64)	5.0 (0.11)	3.1 (0.30)	8.7 (0.42)	7.6 (0.47)	7.2 (0.26)
	I	122.8 (2.45)	97.4 (1.17)	150.7 (5.89)	5.1 (0.12)	3.7 (0.36)	7.9 (0.38)	6.4 (0.40)	6.9 (0.24)
Probability > |F|		0.7961	0.5778	0.0017	0.7846	0.3786	0.2334	0.2088	0.4570
Iole	NI	126.5 (2.53)	119.4 (1.43)	126.1 (4.93)	5.2 (0.12)	2.7 (0.26)	9.9 (0.48)	6.9 (0.43)	6.8 (0.24)
	I	146.2 (2.92)	117.1 (1.41)	107.3 (4.19)	4.5 (0.10)	2.6 (0.25)	10.3 (0.50)	3.2 (0.20)	7.0 (0.25)
Probability > |F|		0.0445	0.7897	0.0222	0.0295	0.0454	0.4009	0.0222	0.5493
Waipio	NI	109.6 (2.19)	100.7 (1.21)	106.6 (4.16)	4.7 (0.11)	1.9 (0.18)	9.0 (0.43)	2.2 (0.14)	7.0 (0.25)
	I	94.8 (1.90)	124.1 (1.49)	109.9 (4.29)	12.4 (0.29)	4.5 (0.44)	9.7 (0.47)	2.2 (0.14)	8.3 (0.29)
Probability > |F|		0.0055	0.0176	0.4955	0.0001	0.0001	0.0184	0.9702	0.0033

* NI = Non-irrigated, I = Irrigated

Table 4.23

Effect of irrigation on ion uptake by amaranth grown at three sites

Site	Irrigation*	g/10 plants							
		Ca	Mg	K	Na	P	S	NO_3	Cl
Kukaiau	NI	1.76	0.78	3.62	0.08	0.21	0.30	1.26	0.18
	I	1.02	0.42	2.18	0.04	0.14	0.15	0.65	0.10
Probability > |F|		0.1244	0.0523	0.1218	0.0885	0.1578	0.0611	0.1138	0.0917
Iole	NI	2.33	1.25	4.44	0.11	0.26	0.44	1.51	0.23
	I	4.86	1.87	5.70	0.13	0.28	0.64	1.36	0.33
Probability > |F|		0.2888	0.5218	0.6999	0.7507	0.9774	0.5609	0.7761	0.5596
Waipio	NI	0.68	0.38	1.28	0.03	0.06	0.13	0.19	0.08
	I	0.58	0.43	1.30	0.08	0.12	0.14	0.18	0.09
Probability > |F|		0.4404	0.4848	0.9677	0.0261	0.0444	0.8752	0.9738	0.6504

* NI = Non-irrigated, I = Irrigated

Table 4.24

Effect of irrigation on total N and nitrate-N concentration in amaranth grown at three sites

Irrigation	Kukaiau		Iole		Waipio	
	Total N	NO_3-N	Total N	NO_3-N	Total N	NO_3-N
	(% dry weight)					
Non-irrigated	4.52	0.47	4.68[a]	0.43[b]	3.15	0.14
Irrigated	4.55	0.40	3.77	0.20	3.41[a]	0.13[b]
Probability > |F|	0.8453	0.2088	0.0167	0.0222	0.3363	0.9702

a, b The two means superscripted by the same small letter are significantly different at 0.0001 probability level (LSD test).

much slower rate. This fact coupled with the lower N contents in the irrigated amaranth relative to their non-irrigated counterpart, in spite of the low soil N in the non-irrigated plots (Table 3.19), seems to indicate that other factors contributed to the poor growth and low utilization of nutrients.

4.2.5 Effects of N and P fertilizers on plant chemical compositions

Only P fertilizer had significant effects on oxalate content in amaranth grown in each site (Table 4.26). The significantly lower total oxalate concentration in P-treated plants in Kukaiau and Waipio and the apparent decrease in Iole plants are in accordance with previous findings by Peck et al. (1980) with table beets. The cation-anion balance concept was inadequate to explain this effect (Table 4.33) since

Table 4.25

Effect of irrigation on total N and nitrate-N uptake by amaranth grown at three sites

Irrigation	Kukaiau		Iole		Waipio	
	Total N	NO_3-N	Total N	NO_3-N	Total N	NO_3-N
	(g/ 10 plants)					
Non-irrigated	2.83	1.26	4.13^a	1.51^b	1.00	0.19
Irrigated	1.65	0.65	1.83	0.51	1.01^a	0.18^b
Probability > |F|	0.1025	0.1138	0.6235	0.7761	0.8576	0.9738

a, b The two means superscripted by the same small letter are significantly different at 0.01 probability level (LSD test).

phosphorus application did not lower cation excess significantly relative to the non-P fertilizer treatments. Peck et al. (1980) found that P fertilizer lowered cation excess. This study showed that in any particular site the sum of tissue cations was not affected by P fertilizer (Table 4.29). Plant K concentration, however, was significantly lowered by P fertilization relative to non-P treated plants in Kukaiau and Waipio. On the other hand, Ca concentration was significantly higher in the P-treated Kukaiau plants and apparently increased in P-treated Iole plants. Mg also decreased, but not significantly in the phosphorus plots in all sites. Therefore, P fertilizer in this study did not alter cation concentration in plants but did affect K and Ca and perhaps Mg differently.

Table 4.26

Effects of fertilizers on various forms of oxalate in amaranth grown at three sites

Oxalate form	Fertilizer	Oxalate concentration ($cmol\ kg^{-1}$ dry weight)					
		Kukaiau*		Iole*		Waipio*	
Total oxalate	Basal	214.6	A	190.7	A	173.3	A
	Basal+N	213.5	A	195.3	A	179.6	A
	Basal+P	184.9	B	176.6	A	145.9	B
Soluble oxalate	Basal	133.1	A	86.0	A	80.6	AB
	Basal+N	105.5	B	73.8	AB	96.9	A
	Basal+P	73.3	C	65.6	B	67.5	B
Insoluble oxalate	Basal	99.8	B	125.1	A	103.5	A
	Basal+N	104.6	B	127.5	A	115.5	A
	Basal+P	121.7	A	132.1	A	107.4	A
Soluble + insoluble oxalate	Basal	232.9	A	211.1	A	184.0	B
	Basal+N	210.1	B	201.3	A	212.4	A
	Basal+P	195.1	B	197.7	A	174.9	B

* Means of the same oxalate form and the same location followed by similar letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

A significant decrease in soluble oxalate was observed in plants wherever phosphorus was applied (Table 4.26). This decrease was likely due to the effects of P fertilizer on decreasing K and probably Mg concentrations in the plants (Table 4.29). Significant increases in insoluble oxalate concentration in P-treated Kukaiau plants may be due to the additional Ca supplied to the plants by triple superphosphate. The increase in the insoluble oxalate in Iole was not significant, however; this is probably related to the fact that the soil there was well supplied with Ca.

The insoluble oxalate content of amaranth in Waipio was not affected significantly by phosphorus fertilization (Table 4.26). The rate of phosphorus application was much less in Waipio (145 kg P ha^{-1}) than in either Kukaiau or Iole (225 kg P ha^{-1}).

Nitrogen fertilizer did not significantly affect various forms of oxalates in Kukaiau and Iole, but did increase concentrations of various forms of oxalate in Waipio (Table 4.26). Previous work showed that addition of N (particularly in the form of nitrate) tended to increase organic acid in plants (Kirkby and Knight, 1977). Ben-Zioni et al. (1970) observed the reduction of nitrate in leaves of corn, tobacco and barley, resulted in build-up of cations in the tissue which in turn was neutralized by malic acid. They observed a stoichiometric relation between the amount of nitrate reduced and malate accumulated.

Correlation of N and P fertilizers with oxalates shows that P has negative relationships with total, soluble and insoluble oxalates in non-irrigated plants, and with soluble oxalate in irrigated plants. N fertilizer exhibited a significant positive relationship with total oxalate in irrigated plants (Table 4.27).

Table 4.27

Correlation between N and P fertilizers with oxalates in irrigated and non-irrigated plots of amaranth

Irrigation	Fertilizer	Correlation coefficient[a] (Probability > |r|)			
		Total	Soluble	Insoluble	Soluble + insoluble
Non-irrigated	N	ns[b]	ns	ns	ns
	P	-0.3809 (0.0500)	-0.5385 (0.0038)	0.6174 (0.0006)	ns
Irrigated	N	0.4363 (0.0292)	ns	ns	ns
	P	ns	-0.4377 (0.0324)	ns	ns

[a]Number of observations = 27

[b]ns = Non-significant

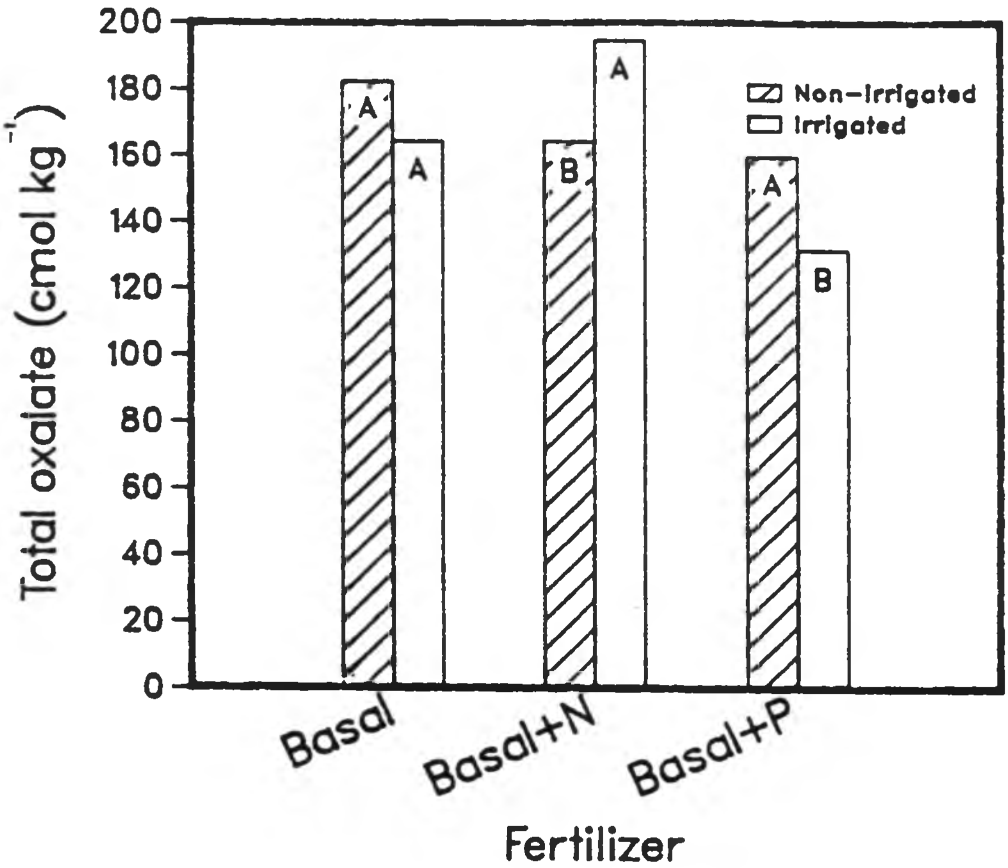
Although irrigation did not have significant effects on oxalates in amaranth grown in the three experimental sites, the effects of irrigation X fertilizer interaction on oxalate, N and ionic concentrations and uptake were significant in Waipio plants (Appendix A). Figure 4.11 illustrates the significant irrigation X fertilizer effect on total oxalate content. Oxalate concentration was significantly higher in plants that received both nitrogen and irrigation. N-fertilized, irrigated plants from Waipio also had higher N uptake than those in non-irrigated plots (Figure 4.12). The higher N uptake was probably a key factor leading to higher oxalate content in N-treated, irrigated plants.

Table 4.28

Effects of fertilizers on the production of various forms of oxalate in amaranth grown at different sites

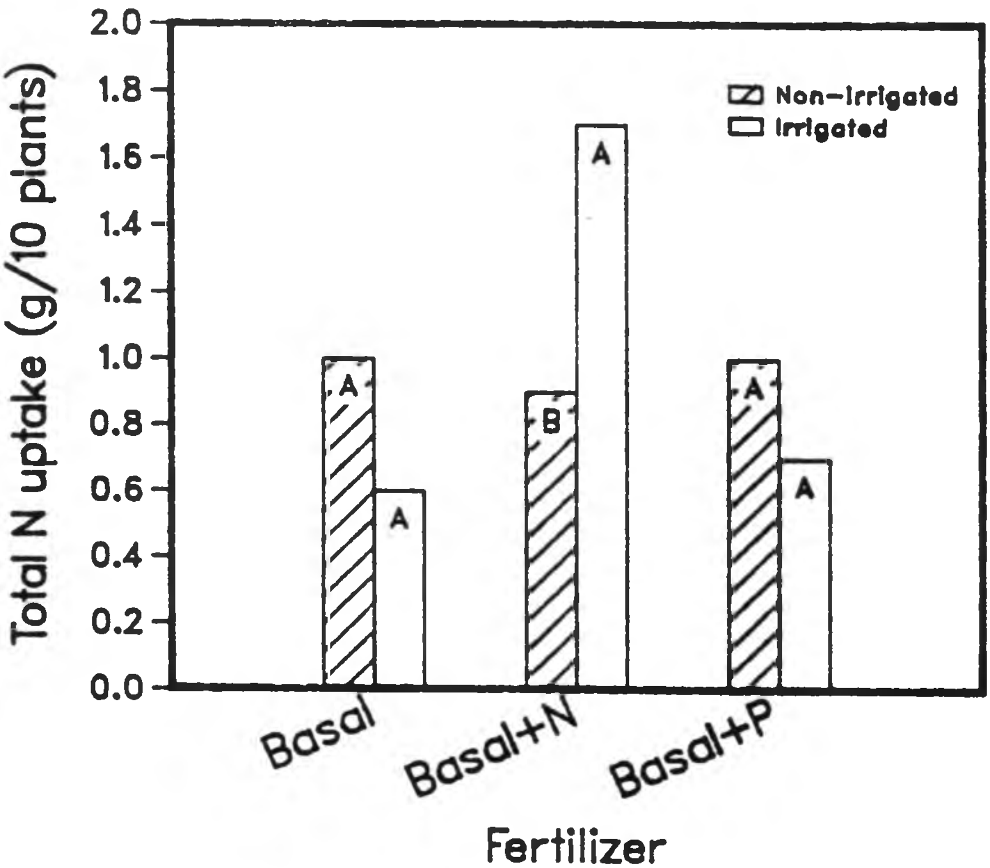
Oxalate	Fertilizer	Oxalate production (g/ 10 plants)		
		Kukaiau*	Iole*	Waipio*
Total oxalate	Basal+P	7.7 A	8.8 A	1.9 B
	Basal+N	3.2 B	8.9 A	2.9 A
	Basal	2.7 B	11.9 A	2.0 AB
Soluble oxalate	Basal+P	2.9 A	3.6 A	0.9 B
	Basal+N	1.5 A	3.0 A	1.6 A
	Basal	1.6 A	4.6 A	0.9 B
Insoluble oxalate	Basal+P	5.2 A	7.2 A	1.4 A
	Basal+N	1.6 B	6.2 A	1.9 A
	Basal	1.3 B	7.8 A	1.2 A
Soluble + insoluble oxalate	Basal+P	8.1 A	10.7 A	2.3 B
	Basal+N	3.1 B	9.2 A	3.4 A
	Basal	2.9 B	12.4 A	2.1 B

* Means of the same oxalate form and the same location followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).



Means of the same fertilizer treatment with the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

Figure 4.11. Effect of irrigation x fertilizer interaction on total oxalate concentration of amaranth grown at Waipio site.



Means of the same fertilizer treatment with the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

Figure 4.12. Effect of irrigation x fertilizer interaction on total N uptake of amaranth grown at Waipio site.

Effects of N and P fertilizers on ionic concentration and uptake of amaranth

The effects of N and P fertilizers on cation concentrations in plants grown in different locations were not consistent (Table 4.29). The high Ca content in triple superphosphate fertilizer probably contributed to the higher plant Ca concentrations at both Kukaiau and Iole sites. Previous work (Peck et al., 1980) showed that P fertilization decreased cation concentrations in plants. The apparent reduction in Mg and K of P-treated Kukaiau plants and Mg in P-treated Iole plants was observed. It appeared that K concentrations in Iole plants were not affected by different fertilizer treatments. On the other hand, K was the dominant cation in plants grown at the Kukaiau site. It is possible that the lower Ca and Mg concentrations in the soil at Kukaiau may have permitted K to be more readily absorbed.

The increase in K concentration in N-fertilized plants at Waipio was the only sign which indicated the effect of N fertilizer on cation concentration in plants. Plants at Kukaiau and Iole sites did not respond to N treatment suggesting that the soils already provided adequate N.

The consistently higher cation uptake in P-treated plants of both Kukaiau and Iole sites suggests that the plant response to P created higher demand for these nutrients (Table 4.31).

N fertilization apparently led to higher cation uptake than other fertilizer treatments in Waipio plants (Table 4.31). This was because N created higher growth demand as indicated by higher dry matter production in N-treated Waipio plants (Table 4.2). Many studies show that

Table 4.29

Effects of N and P fertilizer applications on cation concentrations in amaranth grown at three sites

Site	Fertilizer	Ca*	Mg*	K*	Na*	SC**
		cmol kg^{-1} dry weight				
Kukaiau	Basal	115.3 B	99.3 A	154.6 A	5.2 A	374.3 A
	Basal+N	115.4 B	104.4 A	146.2 AB	4.7 A	370.0 A
	Basal+P	142.4 A	94.3 A	142.0 B	5.2 A	383.9 A
Iole	Basal	131.9 A	120.3 A	119.9 A	5.1 A	377.2 A
	Basal+N	131.6 A	122.0 A	115.7 A	4.4 B	373.7 A
	Basal+P	140.8 A	113.9 A	118.0 A	5.2 A	377.7 A
Waipio	Basal	100.4 A	116.8 A	105.0 B	8.7 A	330.8 A
	Basal+N	103.4 A	109.8 A	117.7 A	8.6 A	339.5 A
	Basal+P	102.8 A	110.7 A	102.0 B	8.4 A	323.8 A

* Means in the same column of each location followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

** Sum of cations concentration.

N affects both absorption and translocation of ions (Barta, 1977). Pretreatment of N deficient roots with nitrate-N resulted in stimulation of strontium and cesium uptake and increased transport of strontium to the shoots (Jackson and Williams, 1968). Anderson and Jackson (1972) reported that nitrate-N pretreatment greatly increased Ca uptake and translocation to shoots. Ammonium and urea pretreatment also increased translocation of Ca.

The increased P, S and Cl concentrations and uptake (Table 4.30, 4.32) in P-treated plants from Kukaiau and Iole was likely due to the effects of P fertilizer on increasing plant growth demand. White (1973) found that the demand for P was associated with the rate of plant growth, or the level of matabolic activity within the tissues, which appeared to have a marked influence on the rate of P uptake.

Effects of N and P fertilizers on cation excess (C-A)

In general, cation excess was not affected by N and P fertilizers. The exception occurred in the N-treated plots in Kukaiau (Table 4.33). According to earlier workers (e.g., Joy, 1964; Kirkby, 1968; Kirkby and Knight, 1977; Kirkby and Mengel, 1967; Peck et al., 1980), nitrogen fertilizer can increase cation excess above that of the controls, while P treatment can decrease cation excess. These trends can be seen in Waipio plants (Table 4.33), although the effects were not significant. The irrigation X fertilizer interaction effect on cation excess of plants was also not significant at any site, although there was a trend of N fertilizer to increase and P fertilizer to decrease oxalate in irrigated plants at Waipio.

Table 4.30

Effects of fertilizers on anion concentrations in amaranth grown at three sites

Site	Fertilizer	P*	S*	NO_3*	Cl*	SA*
		cmol kg^{-1} dry weight				
Kukaiau	Basal	3.4 AB	7.7 B	24.8 B	6.8 B	42.6 B
	Basal+N	2.9 B	7.3 B	47.8 A	6.0 C	64.0 A
	Basal+P	4.0 A	10.0 A	20.5 B	8.4 A	42.9 B
Iole	Basal	2.2 B	10.3 A	20.7 B	6.9 B	40.2 B
	Basal+N	2.0 B	9.5 A	33.6 A	6.3 C	51.4 A
	Basal+P	3.5 A	10.4 A	17.3 B	7.3 A	38.5 B
Waipio	Basal	2.9 B	9.6 A	8.3 A	7.7 A	28.4 A
	Basal+N	2.7 B	9.2 A	12.7 A	7.3 B	31.9 A
	Basal+P	4.0 A	9.2 A	7.8 A	7.9 A	28.9 A

* Means in the same column of each location followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

** Sum of anions concentration.

Table 4.31

Effects of fertilizers on cation uptake by amaranth grown at three sites

Site	Fertilizer	Ca*	Mg*	K*	Na*
		g/ 10 plants			
Kukaiau	Basal	0.67 B	0.33 B	1.70 B	0.03 B
	Basal+N	0.81 B	0.41 B	1.97 B	0.04 B
	Basal+P	2.69 A	1.05 A	5.02 A	0.11 A
Iole	Basal	3.42 A	1.73 A	5.64 A	0.13 A
	Basal+N	2.86 A	1.41 A	4.26 A	0.10 A
	Basal+P	3.92 A	1.44 A	5.05 A	0.13 A
Waipio	Basal	0.54 A	0.35 A	1.05 B	0.04 B
	Basal+N	0.73 A	0.48 A	1.66 A	0.08 A
	Basal+P	0.62 A	0.38 A	1.17 AB	0.05 AB

* Means in the same column of the same location followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

Table 4.32

Effects of fertilizers on anion uptake by amaranth grown at three sites

Site	Fertilizer	P*	S*	NO_3*	Cl*
		g/10 plants			
Kukaiau	Basal	0.08 B	0.10 B	0.51 A	0.07 B
	Basal+N	0.10 B	0.12 B	1.06 A	0.07 B
	Basal+P	0.33 A	0.45 A	1.29 A	0.28 A
Iole	Basal	0.25 A	0.58 A	1.44 A	0.31 A
	Basal+N	0.17 A	0.47 A	1.66 A	0.23 A
	Basal+P	0.37 A	0.53 A	1.27 A	0.28 A
Waipio	Basal	0.07 A	0.12 A	0.13 B	0.07 A
	Basal+N	0.10 A	0.16 A	0.28 A	0.09 A
	Basal+P	0.10 A	0.13 A	0.14 B	0.08 A

* Means in the same column of the same location followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

Table 4.33

Effects of N and P fertilizers on cation excess in amaranth grown at three sites

Fertilizer	Cation excess (cmol kg^{-1} dry weight		
	Kukaiau*	Iole*	Waipio*
Basal	331.6 A	337.0 A	302.5 A
Basal+N	306.1 B	322.4 A	306.7 A
Basal+P	341.1 A	339.2 A	294.9 A

* Means in the same column followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

There are many factors which might have prevented the expected response of cation excess to N and P fertilizers in Kukaiau and Iole plants to be detected but permit it to be expressed in the Waipio plants. The first factors involve N metabolism. N fertilizer applied in urea form was likely to be transformed to nitrate before being absorbed by the plants. The accumulation of nitrate was significantly higher in N-treated plants at Kukaiau and Iole than those treated with the other fertilizers, but such accumulation was not significantly different among different fertilizer treatments in Waipio plants (Table 4.35). This shows that in Kukaiau and Iole, high unassimilated nitrate content led to low cation excess content especially in N-treated Kukaiau and Iole plants. On the other hand, Waipio plants had lower nitrate accumulation (Table 4.35) suggesting that most of the nitrate was assimilated into protein resulting in increased cation excess.

Amaranth grown at the Waipio site may have had higher nitrate reductase activity than those in Kukaiau and Iole. Nitrate reductase activity has been found to be affected by environmental factors, such as light intensity, temperature and soil moisture. Cantliffe (1972b) found that high light intensity promoted the high activity of nitrate reductase. Waipio plants received higher solar radiation than Kukaiau and Iole plants (Table 3.20).

The second factor for the weak causal relationship between cation excess and N and P fertilizer application may involve the use of triple superphosphate as the source of P. P fertilizer was expected to reduce cation excess because it often reduces cation concentration. For example, Peck et al. (1980) found that increasing rates of P fertilizer reduced cation concentration in table beets. Triple superphosphate, however, contains high amounts of Ca resulting in high tissue Ca concentrations in P-treated Kukaiau and Iole plots. These high Ca concentrations are to have prevented P from reducing cation excess in Kukaiau and Iole. On the other hand, Waipio plants received a lower rate of P. Moreover, the lower Ca concentration in these plants (Table 4.29) shows that the cation excess of these P-treated plants are not influenced by Ca to the same extent as P-treated Kukaiau and Iole plants. Apparent response of cation excess to P fertilizer was shown in the Waipio plants (Table 4.33).

Effects of N and P fertilizers on total N and nitrate-N concentrations and uptake

Total N concentration was higher in N-fertilized plants in all sites, while P fertilizer reduced total N concentration (Table 4.34).

Total N uptake was significantly higher in P-fertilized plants in Kukaiau and Iole than in plants treated with basal fertilizer. On the other hand, in Waipio total N uptake was significantly higher in the N-treated plants (Table 4.34).

Table 4.34

Effects of fertilizers N and P on total N concentrations and uptake in amaranth grown at three sites

Fertilizer	Concentration (% dry weight)			Uptake (g/ 10 plants)		
	Kukaiau*	Iole*	Waipio*	Kukaiau*	Iole*	Waipio*
Basal+N	5.06 A	4.68 A	3.53 A	1.74 B	2.81 A	1.27 A
Basal	4.47 B	4.15 A	3.26 AB	1.26 B	2.17 A	0.82 B
Basal+P	4.06 C	4.06 A	3.06 B	3.71 A	4.18 A	0.88 B

* Means in the same column followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

Nitrate-N concentration varied with fertilizer treatments in the same way as total N concentration (Table 4.35). Nitrate-N uptake by Kukaiau and Iole plants was highest in P-treated plants and in N-treated plants in the Waipio plants (Table 4.35).

4.2.6 Relationships between oxalates, nitrate and agroenvironmental factors

All forms of oxalates, with the exception of insoluble oxalate, were significantly negatively correlated with subsoil temperature

Table 4.35

Effects of N and P fertilizers on nitrate-N concentration and uptake by amaranth grown at the three sites

Fertilizer	Concentration (% dry weight)			Uptake (g/ 10 plants)		
	Kukaiau*	Iole*	Waipio*	Kukaiau*	Iole*	Waipio*
Basal+N	0.67 A	0.47 A	0.10 A	1.06 A	1.27 A	0.25 A
Basal	0.35 B	0.29 B	0.12 A	0.51 A	0.73 A	0.13 B
Basal+P	0.29 B	0.24 B	0.11 A	1.29 A	1.19 A	0.14 B

* Means from the same column followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

(Table 4.36). Significant correlations were found more often with soil temperature than with air temperature. All correlations were negative except for that between air temperature and soluble oxalate. Other studies on the relationship between temperature and plant oxalates, although scarce, also indicate the negative relationship between the two variables. Kitchen et al. (1964b) postulated that at high temperatures more oxalic acid was used as a respiratory substrate.

Nitrate-N was also negatively correlated with air and soil temperature (Table 4.36). Temperature can increase nitrate content due to diminished nitrate reductase activities at high temperature (Cantliffe, 1972a). In this study, other factors appeared to override the temperature effect. The most significant factor was soil

Table 4.36

Correlation between amaranth oxalates or nitrate content with air or soil temperature at three experimental sites

Plant Chemical	Correlation coefficient (Probability > |r|)											
	Air temperature				Topsoil temperature				Subsoil temperature			
	Max	Min	Av	Dif*	Max	Min	Av	Dif	Max	Min	Av	Dif
Total oxalate	ns**	ns	ns	-0.5267 (0.0001)	ns (0.0442)	-0.2803 (0.0001)	ns (0.0001)	0.5181 (0.0001)	-0.5646 (0.0001)	-0.5636 (0.0001)	-0.5653 (0.0001)	-0.4332 (0.0001)
Soluble oxalate	ns	0.3449 (0.0132)	ns	ns	ns	ns	ns	0.3976 (0.0039)	-0.3775 (0.0063)	-0.3562 (0.0103)	-0.3717 (0.0072)	-0.4532 (0.0008)
Insoluble oxalate	-0.4256 (0.0019)	-0.3375 (0.0154)	-0.4240 (0.0091)	ns	-0.3593 (0.0096)	-0.3048 (0.0296)	-0.3377	ns	ns	ns	ns	0.2707 (0.0547)
Soluble + Insoluble oxalate	ns	ns	ns	-0.3573 (0.0101)	ns	ns	ns	0.3190 (0.0225)	-0.3620 (0.0091)	-0.3619 (0.0091)	-0.3620 (0.0090)	ns
Nitrate-N	-0.3046 (0.0281)	ns	ns	-0.5439 (0.0001)	ns	-0.4172 (0.0021)	-0.3470 (0.0117)	0.6208 (0.0001)	-0.6206 (0.0001)	-0.6241 (0.0001)	-0.6225 (0.0001)	-0.4134 (0.0023)

* Dif = Difference between maximum and minimum values.
** ns = non-significant.

N content. For example, Waipio, the site with the highest temperature had relatively lower soil N.

Plant oxalate and nitrate were positively correlated with rainfall (Table 4.37). Adequate water supply provided by rains may facilitate ion uptake by roots which enhances oxalate synthesis and nitrate accumulation. Radiation on the other hand, exhibited negative correlation with both oxalates and nitrate (Table 4.37). Long exposure to high light intensity was found to decrease nitrate content due to an increase in nitrate reductase activity (Cantliffe, 1972a and b). The high plant nitrate levels in Iole and Kukaiau relative to those in Waipio can be attributed to the lower radiation and higher soil nitrogen in Iole and Kukaiau than in Waipio.

Nitrate content was also negatively correlated with wind speed (Table 4.37). It has been postulated that factors that cause higher transpiration rates can lead to more rapid nitrate translocation to the site of reduction therefore, resulting in lower nitrate accumulation (Maynard et al., 1976).

Oxalates and nitrate were positively correlated with soil total N, but they showed a negative relationship with the other soil variables (Table 4.38, Figures 4.13-4.17). Earlier work has shown that N assimilation leads to synthesis of organic acid (e.g., Ikeda and Yamada, 1981). In addition, high soil N leads to high N absorption and increased organic acid synthesis. The negative correlation of plant oxalates and nitrate with soil bases was most likely due to the inability of the plants to utilize the soil bases because of low soil N. For example, the Tropeptic Eutrustox in Waipio had a high base

Table 4.37

Correlation between oxalates, nitrate and some climatic factors, including rainfall, radiation, wind speed and relative humidity in amaranth

Chemical composition	Correlation coefficient*** (Probability > |r|						
	Rainfall	Radiation	Wind speed	Relative humidity			
				Maximum	Minimum	Average	Dif*
Total oxalate	0.3740 (0.0063)	-0.4881 (0.0002)	-0.4824 (0.0003)	ns**	ns	ns	-0.4116 (0.0024)
Soluble oxalate	ns	ns	ns	-0.2923 (0.0374)	ns	ns	-0.3062 (0.0289)
Insoluble oxalate	0.4527 (0.0009)	ns	ns	0.4881 (0.0003)	0.5411 (0.0001)	0.5317 (0.0001)	ns
Soluble + insoluble oxalate	0.3265 (0.0194)	-0.3321 (0.0173)	ns	ns	ns	ns	-0.3993 (0.0037)
Nitrate-N	0.3816 (0.0053)	-0.5727 (0.0001)	-0.6507 (0.0001)	ns	0.2720 (0.0511)	ns	-0.3064 (0.0272)

* Dif = Difference between maximum and minimum relative humidity.
** ns = non-significant
*** Number of observations = 54.

Table 4.38

Correlation between amaranth oxalates, nitrate and some soil variables at three experimental sites

	Correlation coefficient** (Probability > |r|)					
Chemical composition	Soil N	Soil Ca	Soil Mg	Soil K	Soil Na	Soil P
Total oxalate	0.5421 (0.0001)	-0.5094 (0.0001)	-0.5571 (0.0001)	-0.3320 (0.0162)	-0.3734 (0.0064)	-0.2477 (0.0766)
Soluble oxalate	ns*	-0.3551 (0.0106)	ns	ns	ns	ns
Insoluble oxalate	ns	ns	ns	ns	ns	ns
Soluble + insoluble oxalate	0.3812 (0.0058)	-0.5075 (0.0001)	-0.4239 (0.0019)	-0.2706 (0.0548)	ns	-0.3042 (0.0300)
Nitrate-N	0.5983 (0.0001)	-0.5495 (0.0001)	-0.6154 (0.0001)	-0.4742 (0.0004)	-0.3832 (0.0050)	ns

* ns = non-significant
** Number of observations = 54.

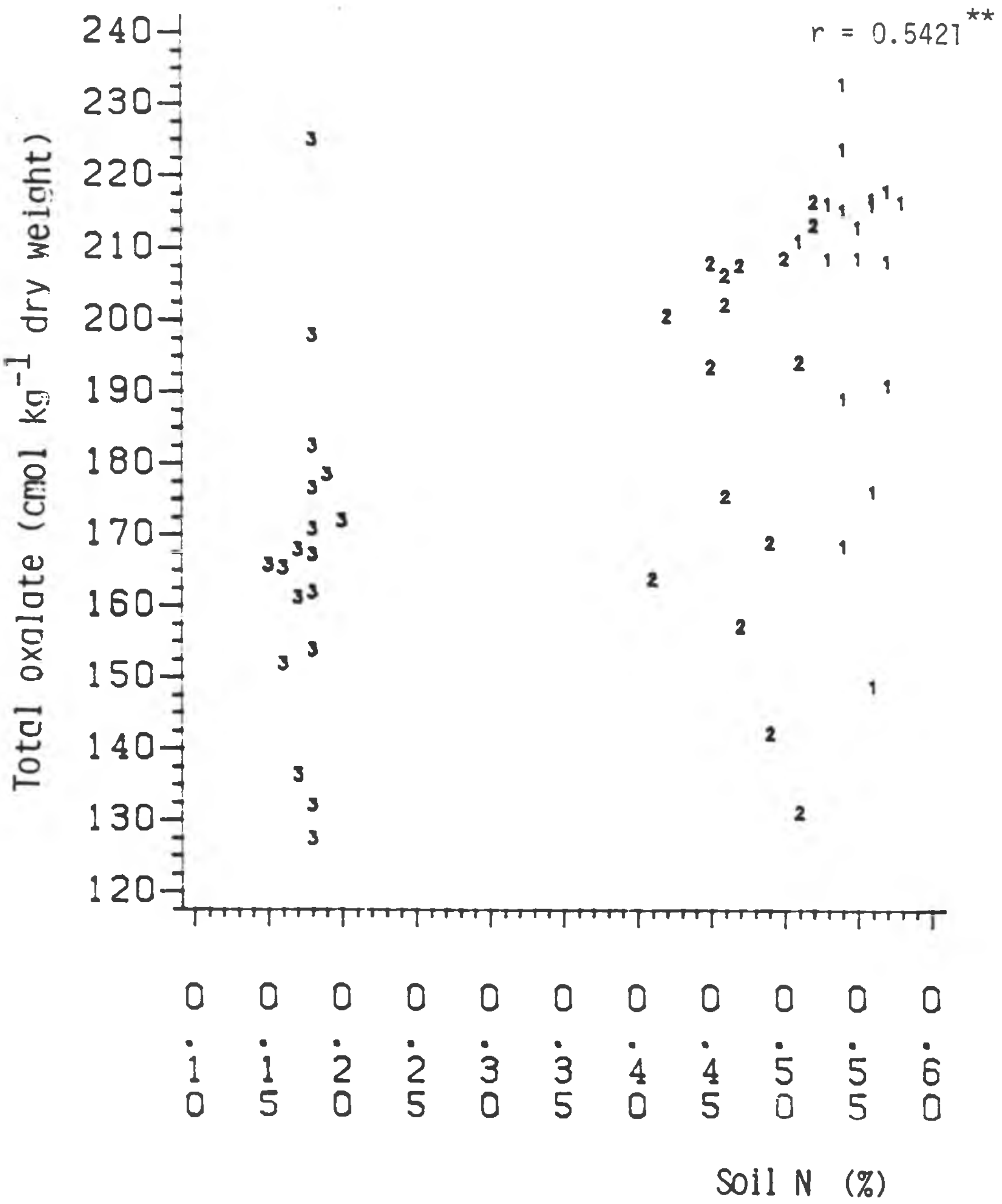


Figure 4.13. Relationship between tissue total oxalate of amaranth and soil nitrogen from experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

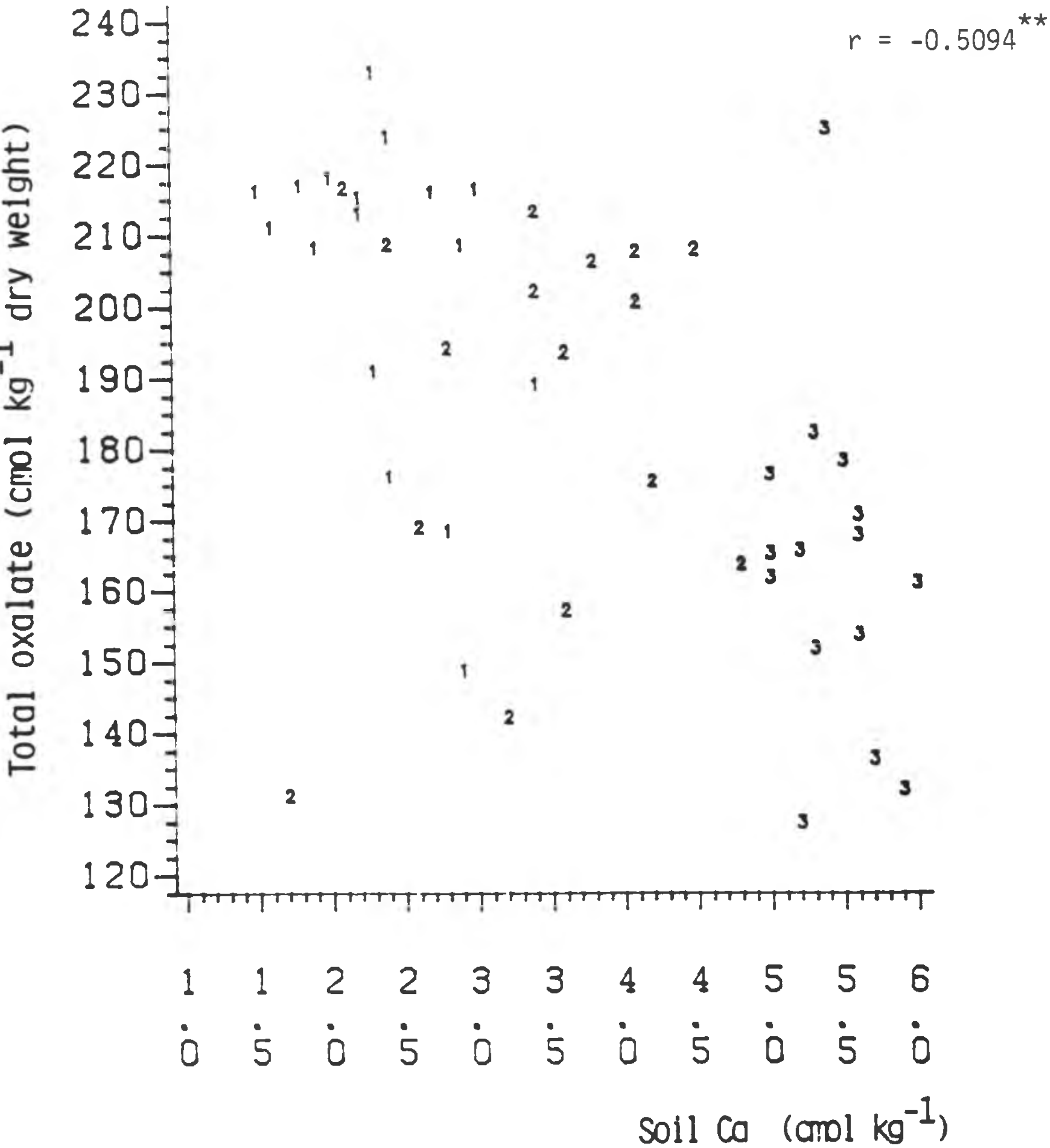


Figure 4.14. Relationship between tissue total oxalate of amaranth and soil Ca from experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

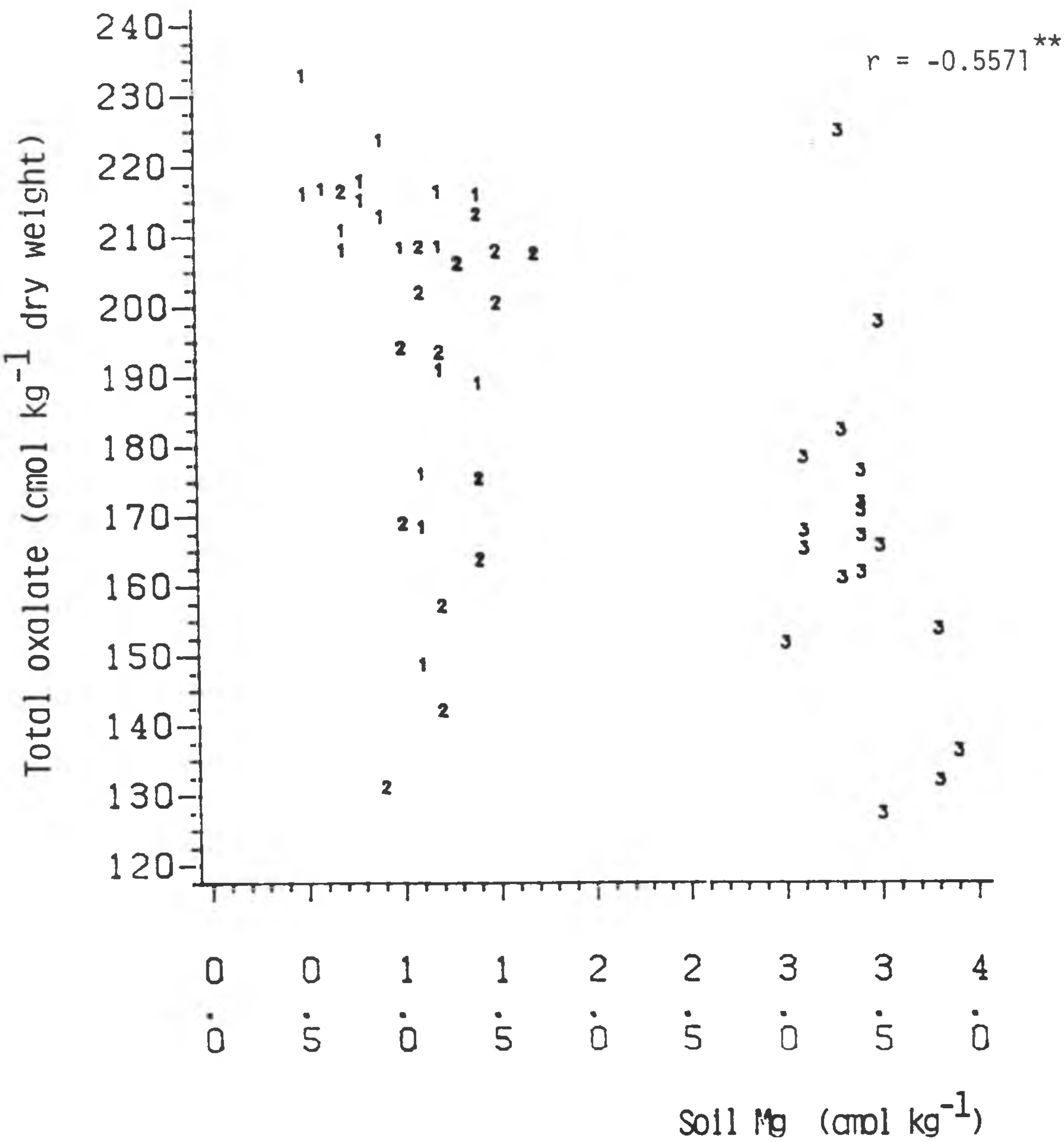


Figure 4.15. Relationship between tissue total oxalate of amaranth and soil Mg from experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

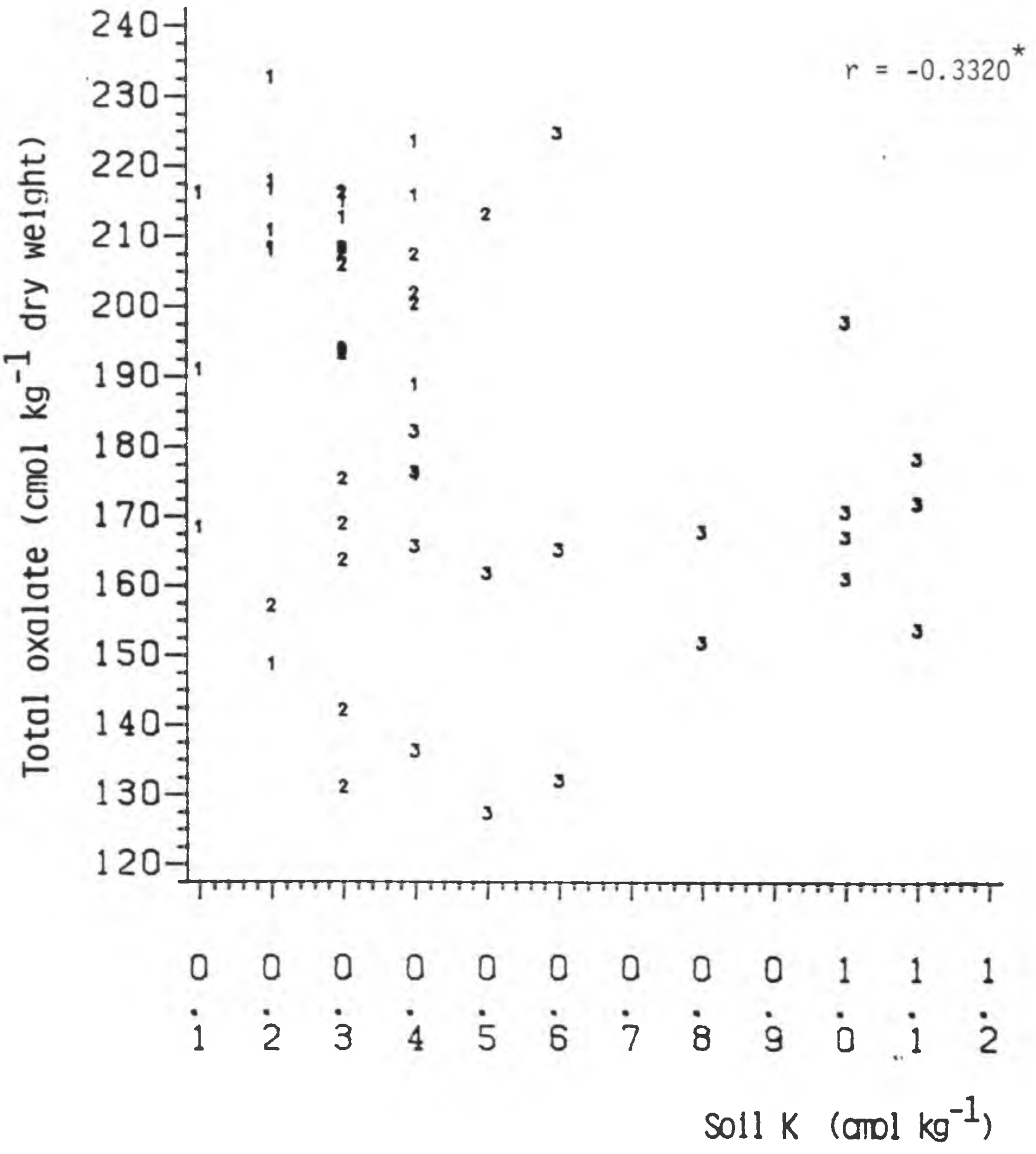


Figure 4.16. Relationship between tissue total oxalate of amaranth and soil K from experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

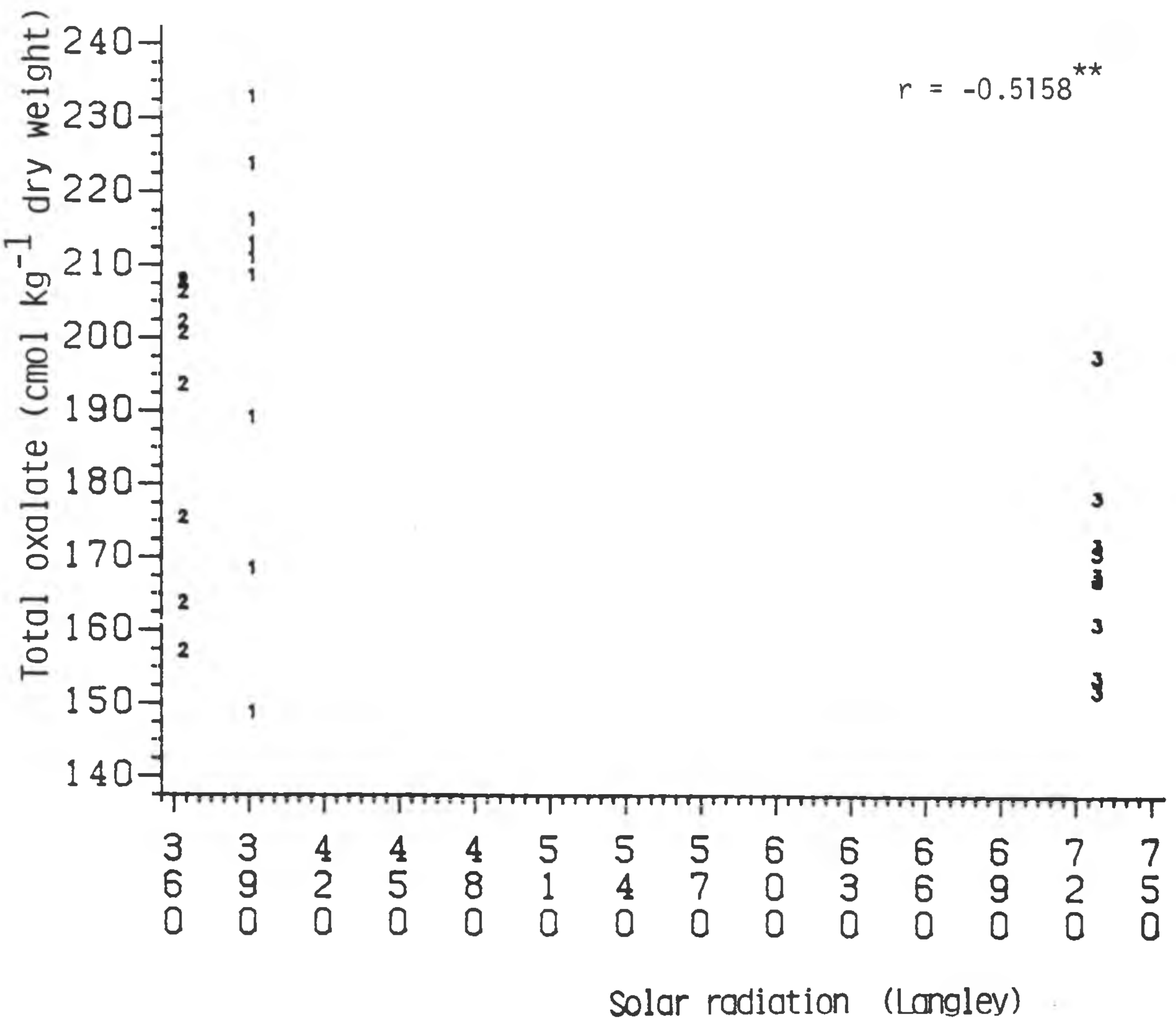


Figure 4.17. Relationship between tissue total oxalate of amaranth and solar radiation from non-irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

status but low N. As a consequence, the plants at this site suffered mild N stress and did not absorb other nutrients efficiently. The low level of N and low cation uptake led to low contents of oxalate and nitrate despite the high base status of the soil.

Soil P was negatively correlated with oxalates (Table 4.38) and this is consistent with the tendency of P to reduce the cation excess in plants.

Multiple regression analysis of the relationships between oxalate, nitrate and agroclimatic factors

Multiple regression analysis of data from irrigated and non-irrigated plots were conducted separately to minimize the variance associated with irrigation treatments described earlier in section 4.2.4. Irrigation treatments by themselves did not result in significant effects on oxalate and nitrate concentrations in amaranth, with the exception of the insoluble oxalate and nitrate in Iole plants (Tables 4.20, 4.24). Significant interaction effects, however, were found. For example, the effects of site x irrigation and site x irrigation x fertilizer on nitrate-N content were significant (Appendix A).

The regression equation for total oxalate concentration in non-irrigated amaranth is presented in Table 4.39. The negative relationships of oxalate concentration with mean solar radiation and P fertilizer rate were as shown in Figures 4.17, 4.18. P fertilizer has decreased oxalate in table beets (Peck et al., 1980) apparently because P fertilizer decreased uptake and concentration of cations by plants and therefore decreased cation excess. Soil Mg and K contributed positively to oxalate production since their uptake increase cation

Table 4.39

Multiple regression equation for total oxalate concentration in amaranth from non-irrigated plots of three experimental sites

Variable*	Regression coefficient	Standard error	t	Probability > |t|
Intercept	225.261	7.4549	30.217	0.0001
SRSQ	-0.000025	0.000061	-0.400	0.6934
PLEVEL	-0.0894	0.0421	-2.121	0.0454
SOLMG	36.3598	13.5733	-2.679	0.0137
SOLK	84.7203	42.4200	1.997	0.0583

Model r^2 = 0.6123

Model Adj. r^2 = 0.5419

*SRSQ = Square of solar radiation
PLEVEL = Fertilizer P rate
SOLMG = Soil Mg content
SOLK = Soil K content.

excess. The negative correlations of soil Mg and K with oxalate (Figures 4.15 and 4.16) were probably due to their interaction with soil N. Although soil Mg and K were high at the Waipio site, the plants did not absorb a large amount of Mg and K due to low N supply.

In the irrigated treatments, solar radiation gave rise to a positive parameter estimate (Table 4.40) in spite of its negative correlation with total oxalate (Figure 4.19). The difference between maximum and minimum air temperature, however, gave rise to negative regression coefficient. This is consistent with the negative

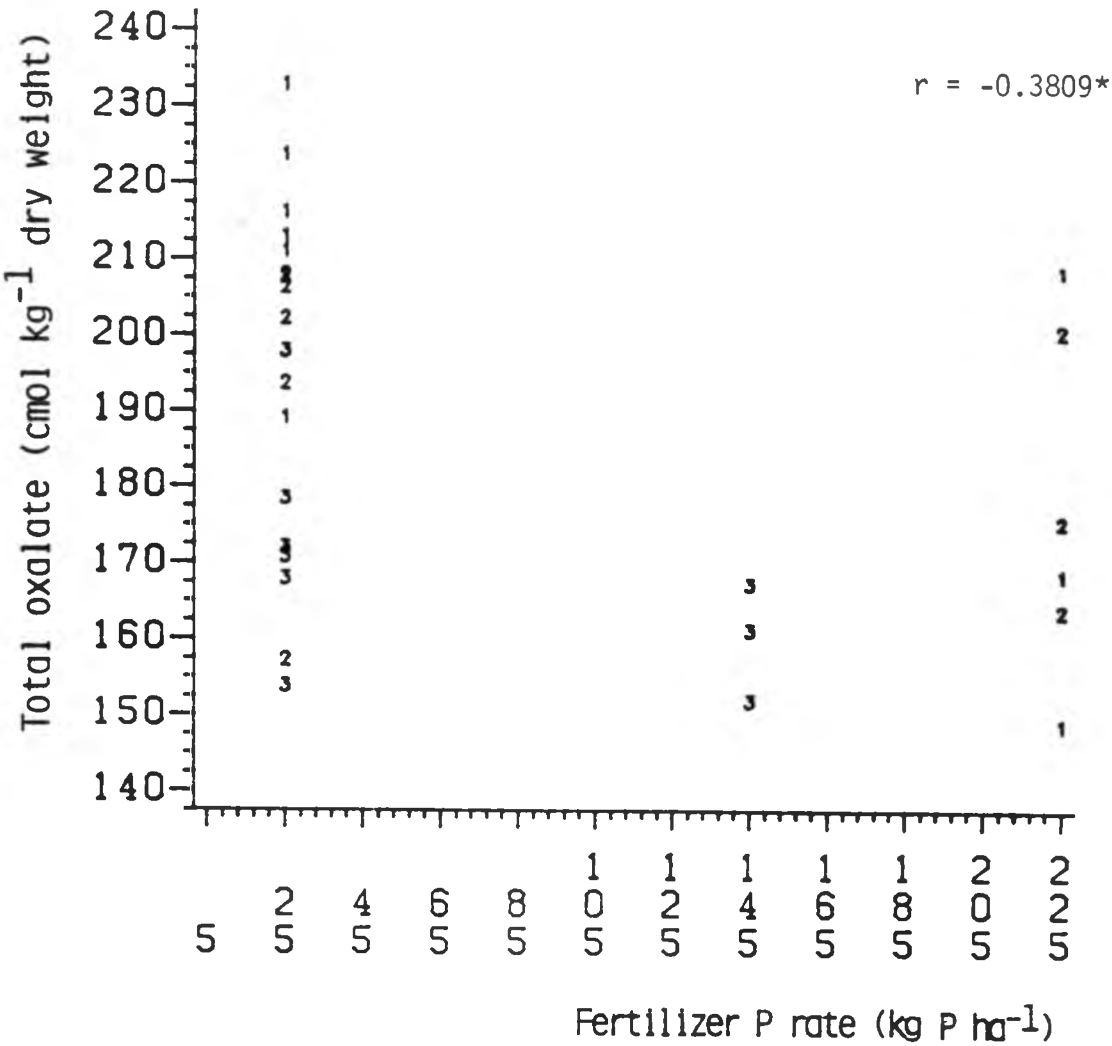


Figure 4.18. Relationship between tissue total oxalate of amaranth and fertilizer P rate from non-irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

relationship between this variable and total oxalate (Appendix D). The difference between maximum and minimum air temperature exhibited curvilinear relationship with total oxalate. To take into account the non-linear relationship in the regression studies the difference between maximum and minimum air temperature was squared. Solar radiation and the square of the difference between maximum and minimum temperature were highly correlated ($r = 0.9996$, Appendix D). This may be due to clear skies giving rise to high radiation and warm temperature during the day and low temperature at night. The fact that the two variables gave rise to opposite signs of the regression coefficient (Table 4.40) indicated that they contributed to oxalate production in different ways.

Fertilizer N rate also gave rise to a positive regression coefficient which was consistent with the positive correlation between this variable and total oxalate (Figure 4.20).

The regression model for soluble oxalate in non-irrigated amaranth with the related statistics is shown in Table 4.41. Not unexpectedly soil K explained a significant amount of variance in soluble oxalate as soluble oxalate occurred primarily as potassium oxalate. P fertilizer rate and soil Ca were negatively correlated with soluble oxalate and the relationship was in accordance with their negative relationships with soluble oxalate (Figures 4.21, 4.22, Appendix C). P fertilizer is also a source of Ca for the plants. The regression coefficient of soil P was positive (Table 4.41), however, it was negatively related to soluble oxalate as shown in Figure 4.14, Appendix C. P usually brings about a reduction in cation excess which, in turn, results in a decrease in oxalate concentration. It is likely

Table 4.40

Multiple regression equation for total oxalate concentration in amaranth from irrigated plots at three experimental sites

Variable*	Regression coefficient	Standard error	t	Probability > |t|
Intercept	1991.572	659.811	3.018	0.0068
SRSQ	0.0059	0.0022	2.688	0.0141
NLEVEL	0.1791	0.0503	3.557	0.0020
SOLK	105.048	54.8168	1.916	0.0697
AIR4SQ	-30.9963	11.2800	-2.748	0.0124

Model r^2 = 0.6076

Model Adj. r^2 = 0.5291

* SRSQ = Square of solar radiation

NLEVEL = Fertilizer N rate

SOLK = Soil K concentration

AIR4SQ = Square of the difference between maximum and minimum temperature.

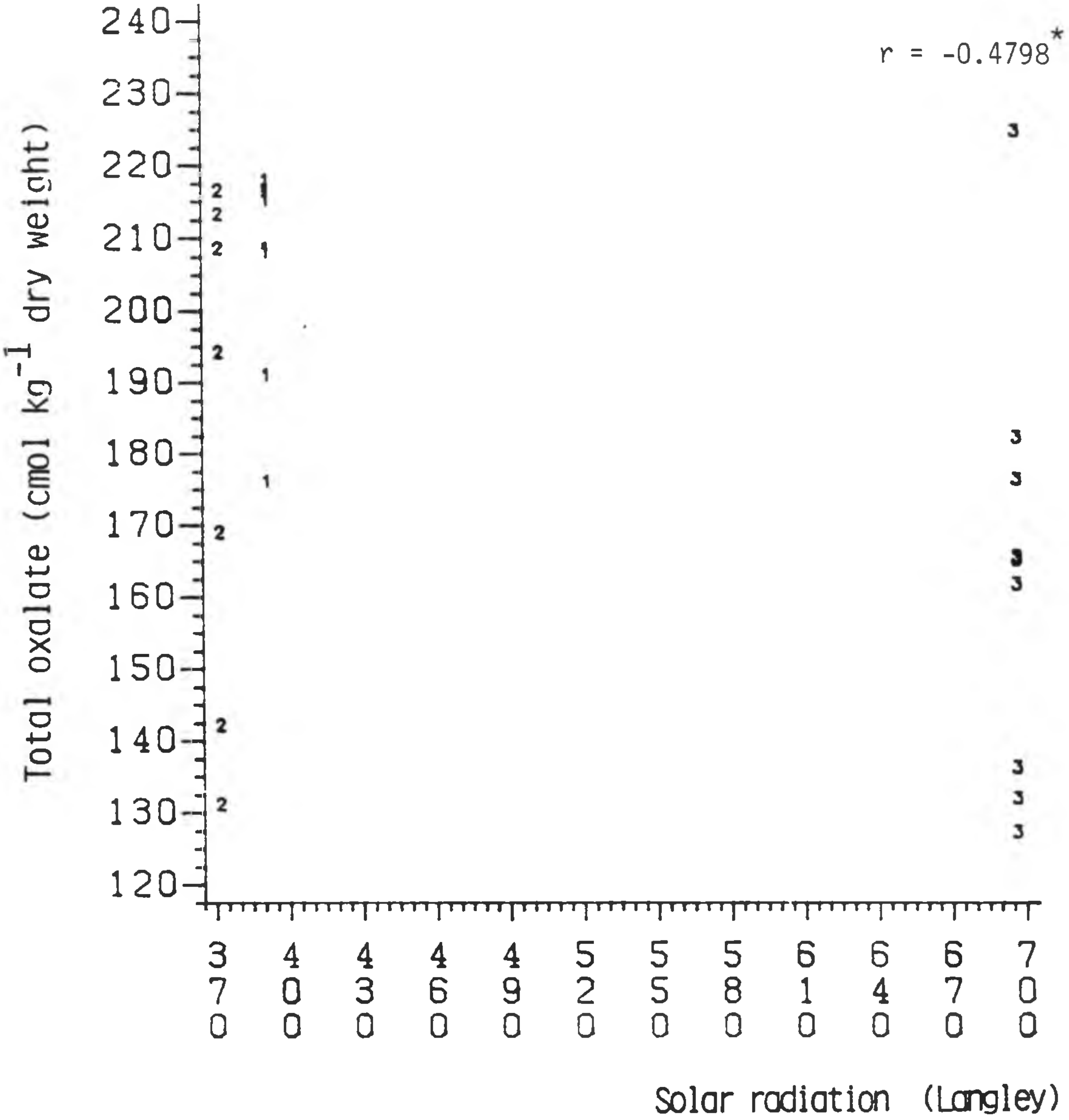


Figure 4.19. Relationship between tissue total oxalate of amaranth and solar radiation from irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

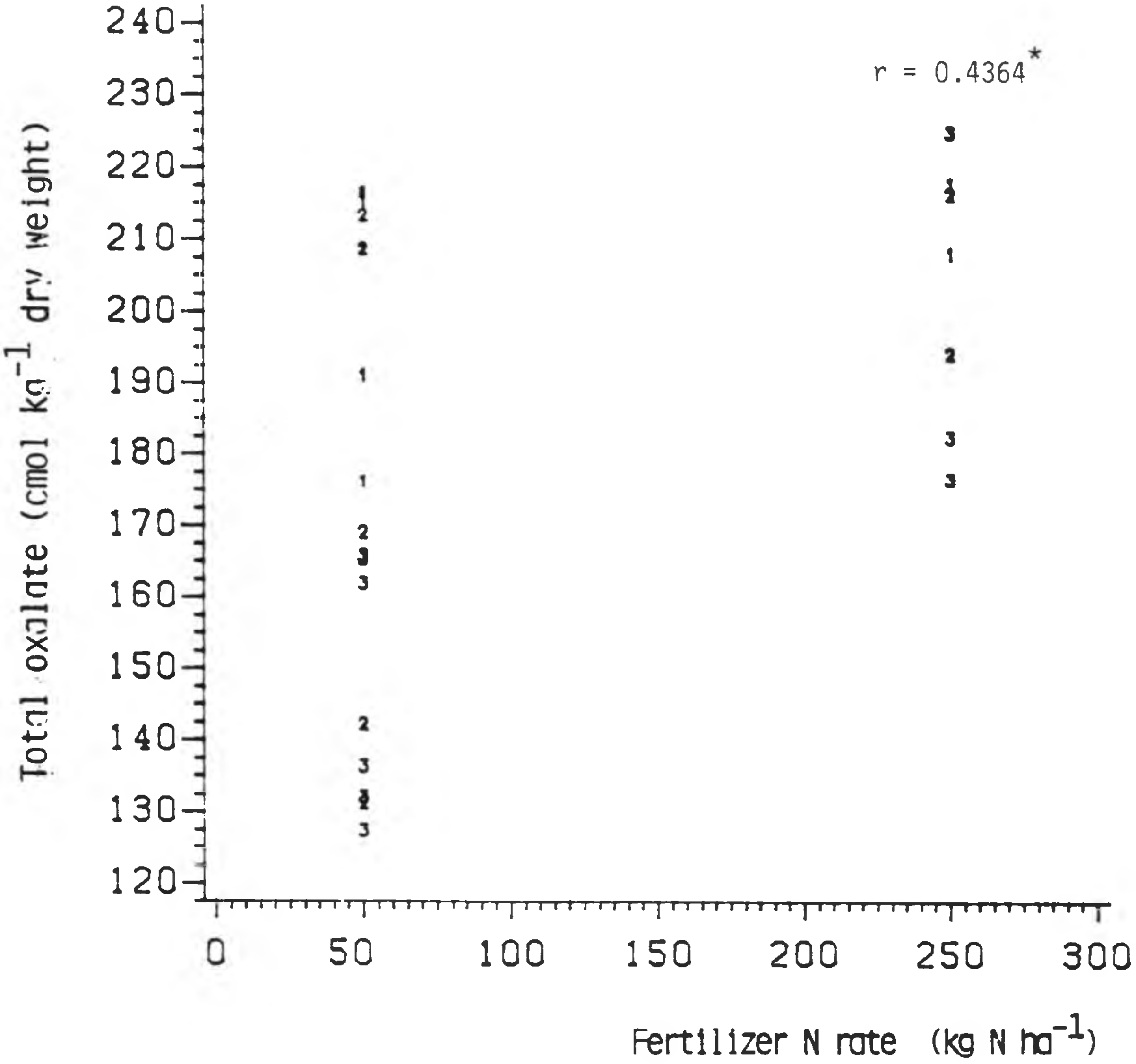


Figure 4.20. Relationship between tissue total oxalate of amaranth and fertilizer N rate from irrigated plot of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

Table 4.41

Multiple regression equation for soluble oxalate concentration in amaranth from non-irrigated plots of three experimental sites

Variable*	Regression coefficient	Standard error	t	Probability > |t|
Intercept	113.253	20.3643	5.561	0.0001
SOLK	56.5055	21.8189	2.590	0.0167
PLEVEL	-0.1698	0.0603	-2.818	0.0100
SOLCA	-18.7353	4.8909	-3.831	0.0009
SOLP	0.4673	0.2815	1.660	0.1110

Model r^2 = 0.6359

Model Adj. r^2 = 0.5698

* SOLK = Soil K concentration
PLEVEL = Fertilizer P rate
SOLCA = Soil Ca concentration
SOLP = Soil P concentration

that fertilizer P affected plant growth more than initial soil P and this is supported by the fact that soil P did little to explain the variance in soluble oxalate (Table 4.41). Because soil P was measured at harvest, it included both the P applied as fertilizer and initial soil P. In the multiple regression analysis, both variables were retained but only P level was significant. This is due to the fact that P level and soil P were highly correlated.

The regression analysis of soluble oxalate in irrigated plants is shown in Table 4.42. In accordance with the positive relationship

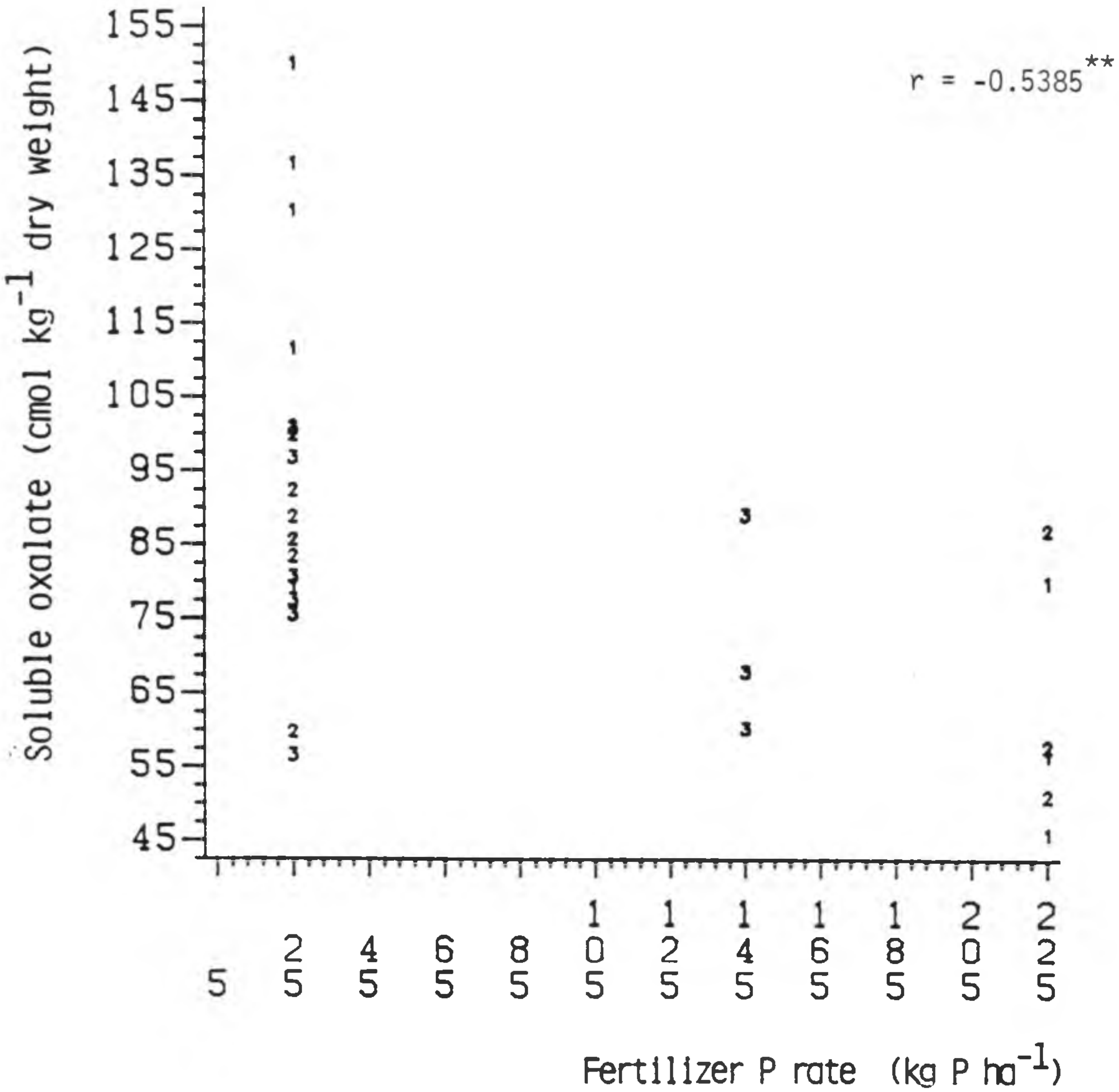


Figure 4.21. Relationship between tissue soluble oxalate of amaranth and fertilizer P rate from non-irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

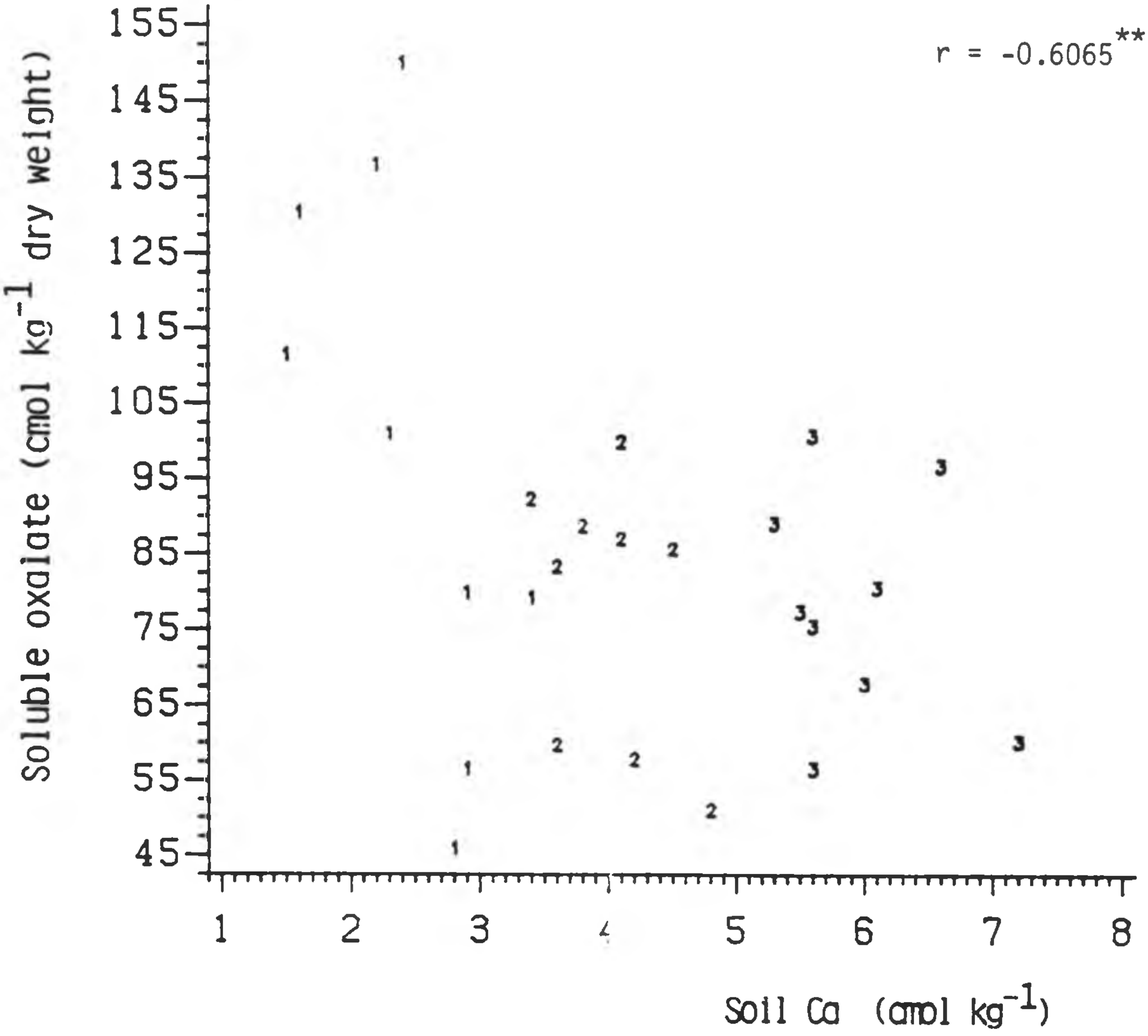


Figure 4.22. Relationship between tissue soluble oxalate of amaranth and soil Ca from non-irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

Table 4.42

Multiple regression equation for soluble oxalate concentration in amaranth from irrigated plots of three experimental sites

Variable*	Regression coefficient	Standard error	t	Probability > |t|
Intercept	-109.043	47.0516	-2.318	0.0306
AIR2	13.9927	3.1128	4.495	0.0002
PLEVEL	-0.1439	0.0430	-3.350	0.0031

Model r^2 = 0.5880

Model Adj. r^2 = 0.5488

* AIR2 = Minimum air temperature

PLEVEL = Fertilizer P rate.

between soluble oxalate and minimum air temperature (Figure 4.23), this variable also gave rise to a positive parameter estimate. The effect of air temperature on soluble oxalate concentration was positive while the effect on total and insoluble oxalate was negative. Fertilizer P rate also produced negative regression coefficient in accordance with its negative relationship with soluble oxalate (Figure 4.24).

The regression model for insoluble oxalate concentration in non-irrigated plants is shown in Table 4.43. Only variables related to P supply significantly influenced insoluble oxalate. Although soil P was not significantly related with insoluble oxalate (Appendix C), the regression coefficient was significantly negative in this equation. The reason put forward earlier that P being an anion tends to decrease

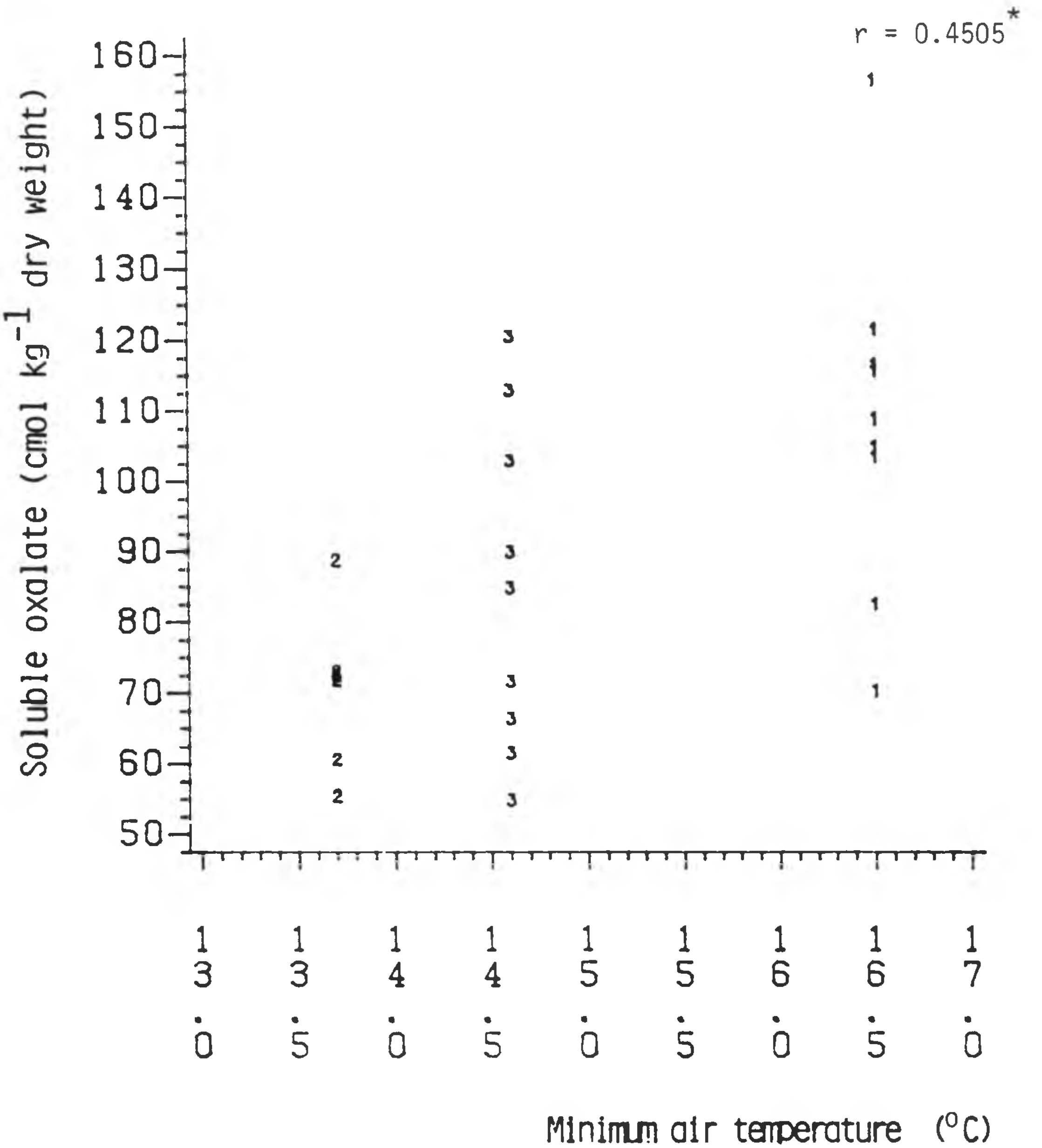


Figure 4.23. Relationship between tissue soluble oxalate of amaranth and minimum air temperature from irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

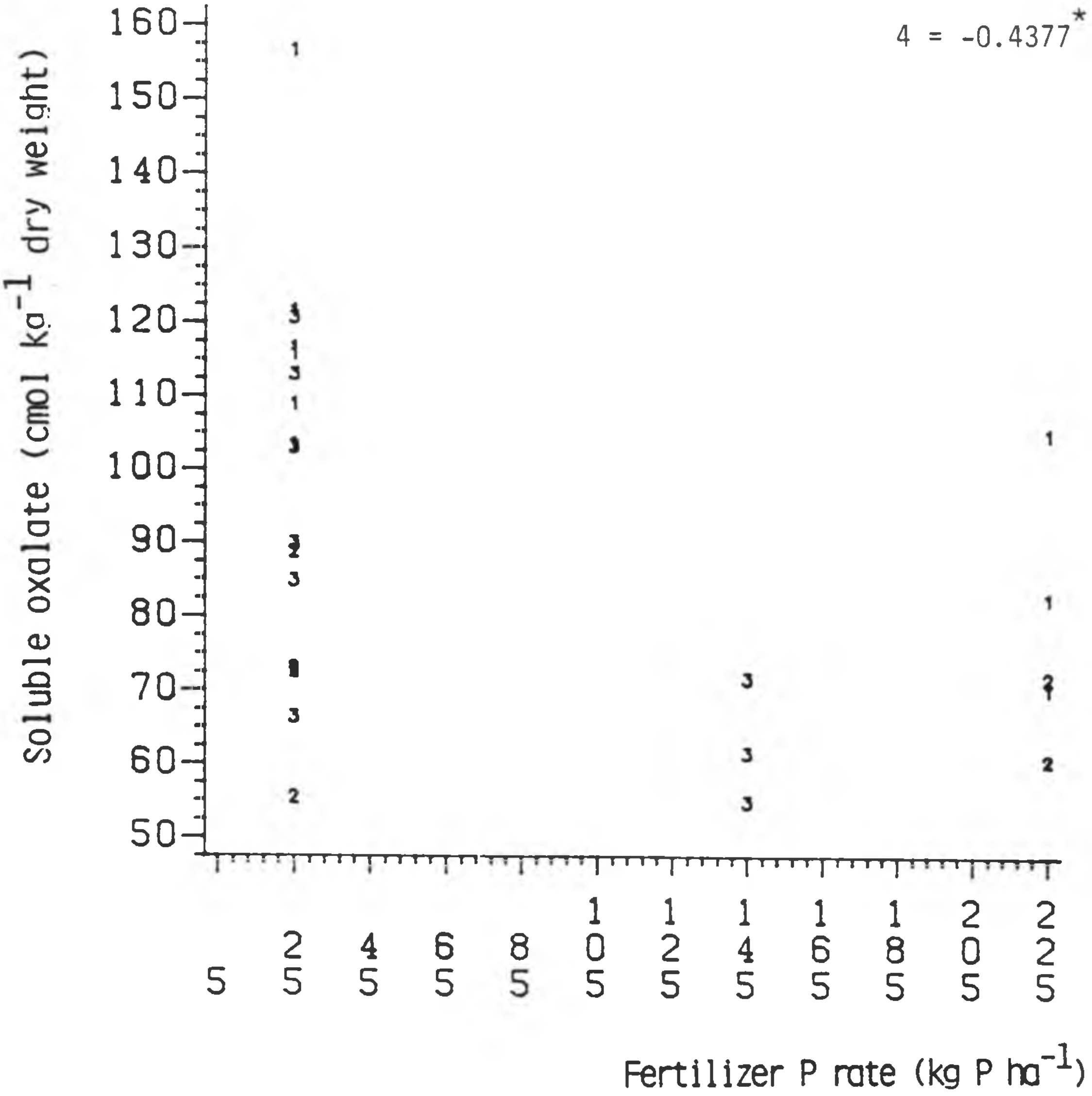


Figure 4.24. Relationship between tissue soluble oxalate of amaranth and fertilizer P rate from irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

Table 4.43

Multiple regression equation for insoluble oxalate concentration in amaranth from non-irrigated plots of three experimental sites

Variable*	Regression coefficient	Standard error	t	Probability > |t|
Intercept	135.991	8.8214	15.516	0.0001
SOLP	-0.5121	0.1386	-3.696	0.0011
PLEVEL	0.1659	0.0277	5.997	0.0001

Model r^2 = 0.6057
Model Adj. r^2 = 0.5728

* SOLP = Soil P concentration
PLEVEL = Fertilizer P rate.

the cation excess and therefore, oxalate production applies here as well. The regression coefficient of fertilizer P rate was significantly positive which is consistent with the significant positive relationship between insoluble oxalate and fertilizer P rate (Figure 4.25). The additional Ca supplied to plants by P fertilizer probably led to high Ca oxalate content in plants receiving this treatment.

The regression model for insoluble oxalate in irrigated plants is shown in Table 4.44. Seventy-five percent of the variance in insoluble oxalate was explained by this model in contrast to 57% for soluble oxalate in non-irrigated plants, 55% for soluble oxalate in irrigated plants and 57% for insoluble oxalate in non-irrigated plants. P-related variables were significantly related as were fertilizer N rate and average air temperature. Fertilizer N rate was not

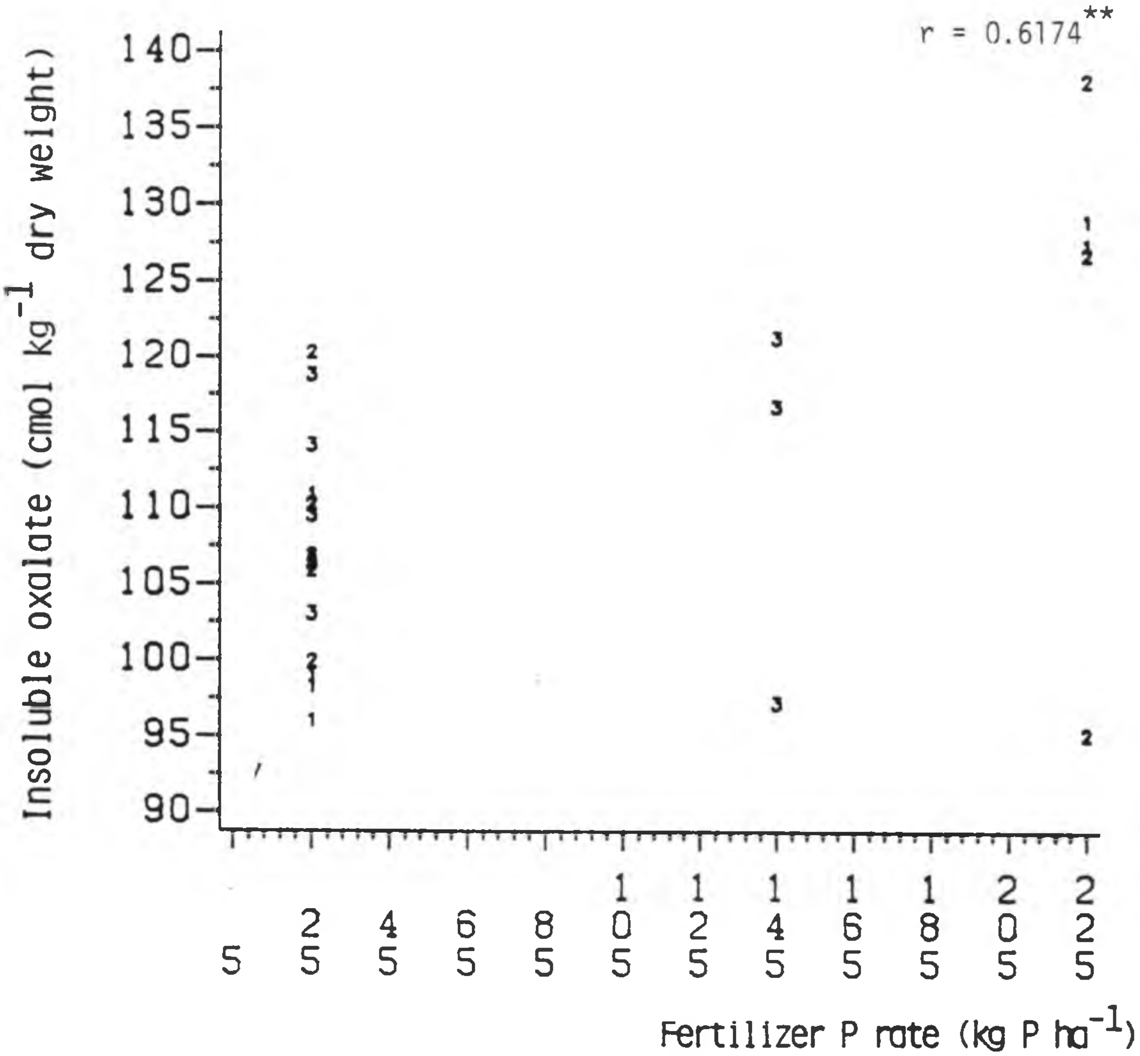


Figure 4.25. Relationship between tissue insoluble oxalate of amaranth and fertilizer P rate from non-irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

Table 4.44

Multiple regression equation for insoluble oxalate concentration in amaranth from irrigated plots of three experimental sites

Variable*	Regression coefficient	Standard error	t	Probability > |t|
Intercept	441.555	42.6866	10.346	0.0001
AIR3	-16.5982	2.0681	-8.026	0.0001
NLEVEL	0.0754	0.0295	2.552	0.0190
PLEVEL	0.0512	0.0335	1.528	0.1422

Model r^2 = 0.7840

Model Adj. r^2 = 0.7516

* AIR3 = Average air temperature
NLEVEL = Fertilizer N rate
PLEVEL = Fertilizer P rate

significantly related with insoluble oxalate (Table 4.27), but the regression coefficient was significantly positive. The role of N in organic acid synthesis in plants is well known. The process of N assimilation leads to the synthesis of organic acid as shown, for example, by the study by Ikeda and Yamada (1981). For this regression average air temperature was negative as was the case for simple correlation (Figure 4.26).

The regression model for nitrate-N concentration in non-irrigated plants is shown in Table 4.45. Fertilizer N contributed most to explaining the variance in nitrate-N concentration. The regression

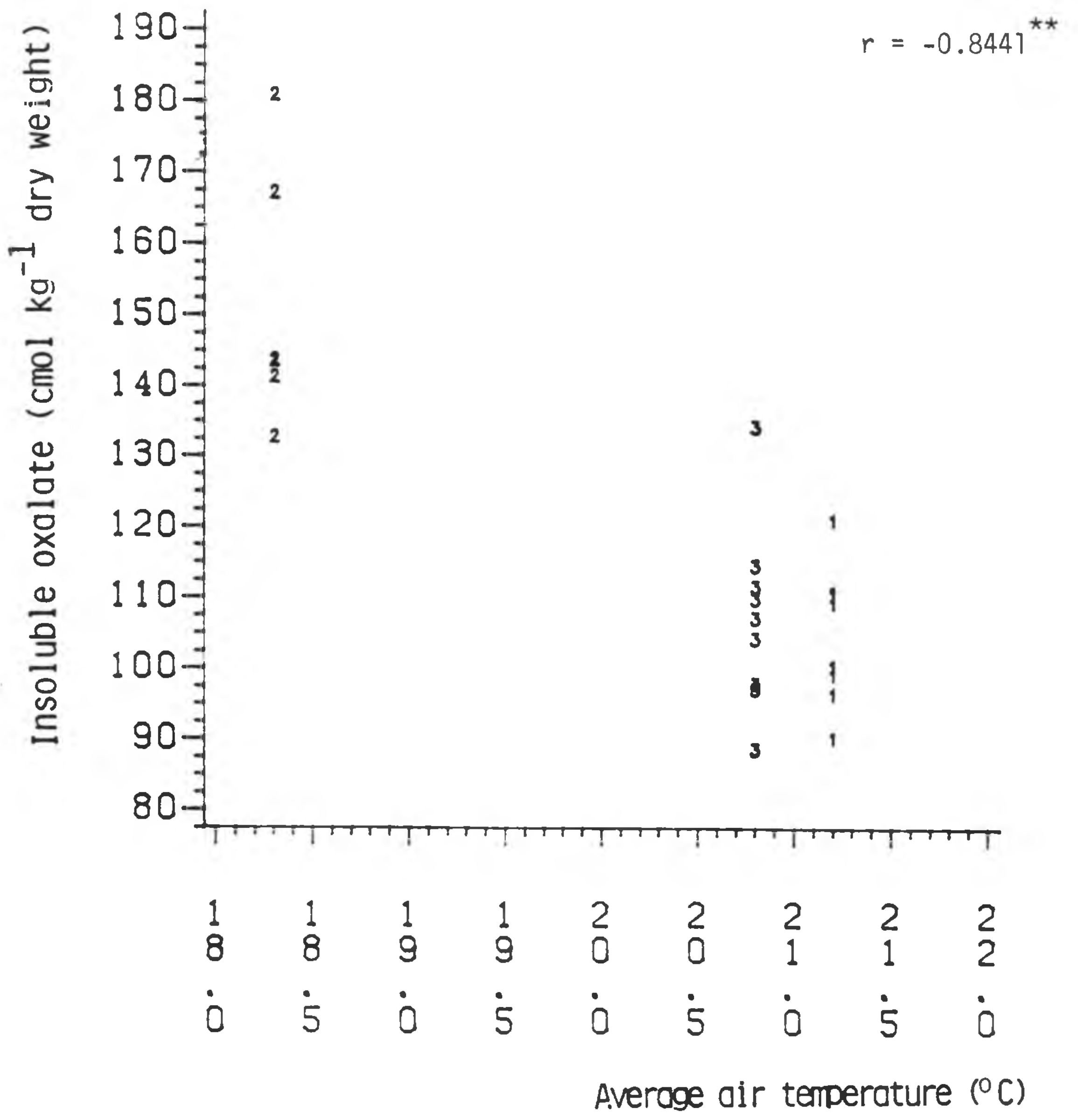


Figure 4.26. Relationship between tissue insoluble oxalate of amaranth and average air temperature from irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

Table 4.45

Multiple regression equation for nitrate-N concentration in amaranth from non-irrigated plots of three experimental sites

Variable*	Regression coefficient	Standard error	t	Probability > |t|
Intercept	39.8414	4.6198	8.624	0.0001
WSPSQ	-0.3053	0.2506	-1.218	0.2360
NLEVEL	0.0764	0.0164	4.657	0.0001
SOLMG	-18.5415	5.6715	-3.269	0.0035
SOLK	39.0297	18.5464	2.104	0.0470

Model r^2 = 0.7861

Model Adj. r^2 = 0.7472

* WSPSQ = Square of wind speed
NLEVEL = Fertilizer N rate
SOLMG = Soil Mg concentration
SOLK = Soil K concentration.

coefficient was positive, and consistent with the relationship between the two variables (Figure 4.27). Initial soil N did not significantly influence plant nitrate concentration probably due to its low level compared with applied fertilizer N. The regression coefficient of the square of wind speed was negative in accordance with its negative relationship with nitrate-N (Figure 4.28). High wind speed usually increases transpiration rate. According to Maynard et al. (1976) transpiration also accelerates the translocation of nitrate to the site of reduction. The regression coefficient of soil Mg was negative in

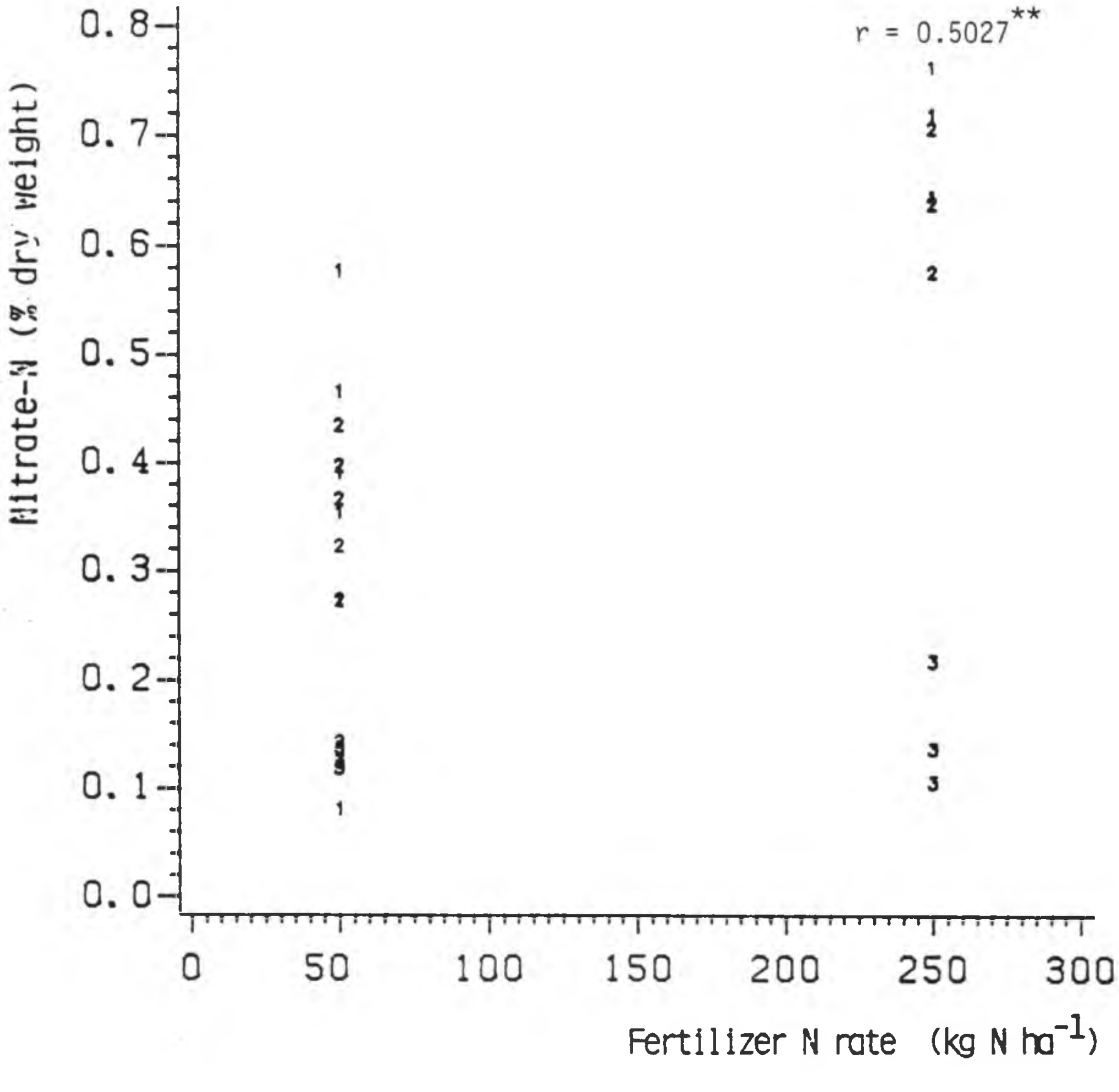


Figure 4.27. Relationship between tissue nitrate-N concentration of amaranth and fertilizer N rate from non-irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

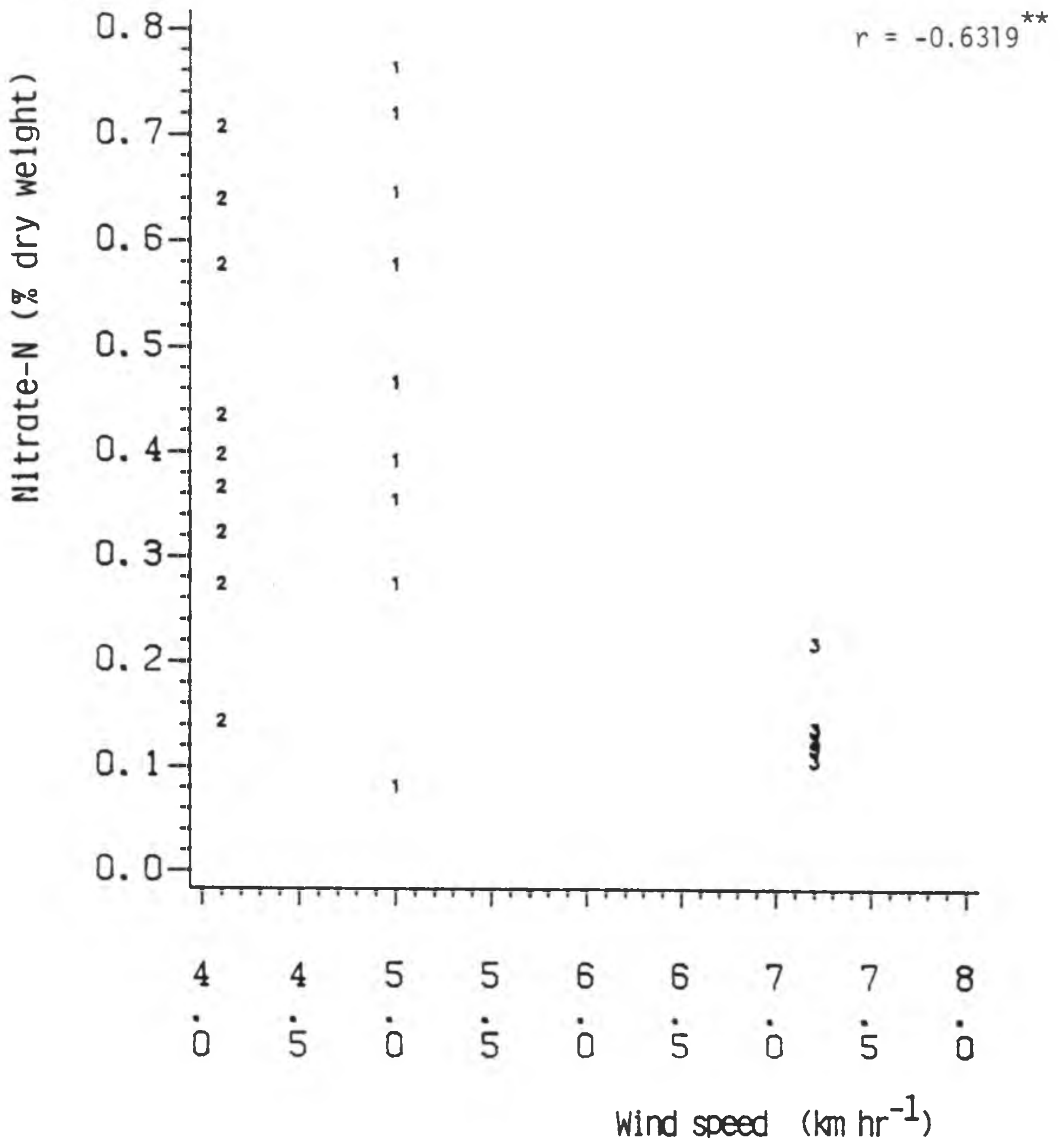


Figure 4.28. Relationship between tissue nitrate-N concentration of amaranth and wind speed from non-irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

accordance with its negative relationship with nitrate-N (Figure 4.29). On the other hand, the regression coefficient of soil K was positive despite its negative relationship with nitrate-N (Figure 4.30). The change in sign is probably due to the highly correlated nature of soil Mg and soil K (Appendix C). Moreover, K is often the cation accompanying nitrate movement from the root to the shoot (Minotti, 1968). K fertilizer also increased nitrate content in some vegetables (Cantliffe, 1973).

The results of the multiple regression analysis of nitrate-N concentration in irrigated amaranth are shown in Table 4.46. In addition to N fertilizer rate (Figure 4.31) and soil N (Figure 4.32), minimum air temperature also helped to explain the variance in the nitrate-N concentration. Minimum air temperature was squared because it showed a curvilinear relationship with nitrate-N (Figure 4.33). The positive relationship between minimum air temperature and nitrate-N concentration shown in Figure 4.33 was apparent in the multiple regression analysis. This is consistent with the observation that high temperatures increased plant nitrate content. This effect was attributed to a combination of reduced nitrate reductase activity and higher availability of soil nitrate due to increased microbial activity.

4.3 Response of cassava to environmental factors

In this section emphasis is placed on the results concerning the effects of environmental factors on nutrient and antinutrient contents of cassava leaves.

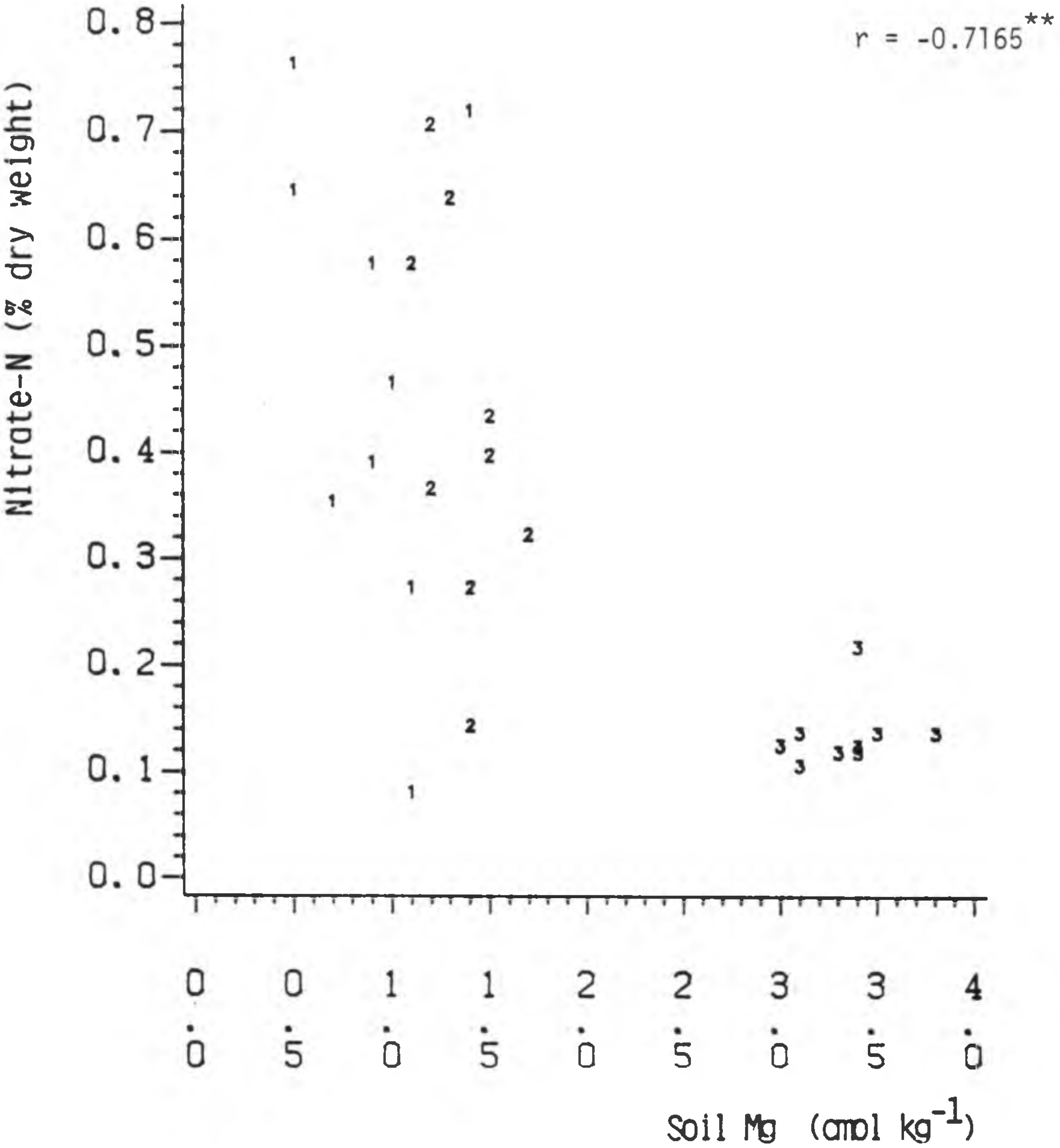


Figure 4.29. Relationship between tissue nitrate-N concentration of amaranth and soil Mg from non-irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

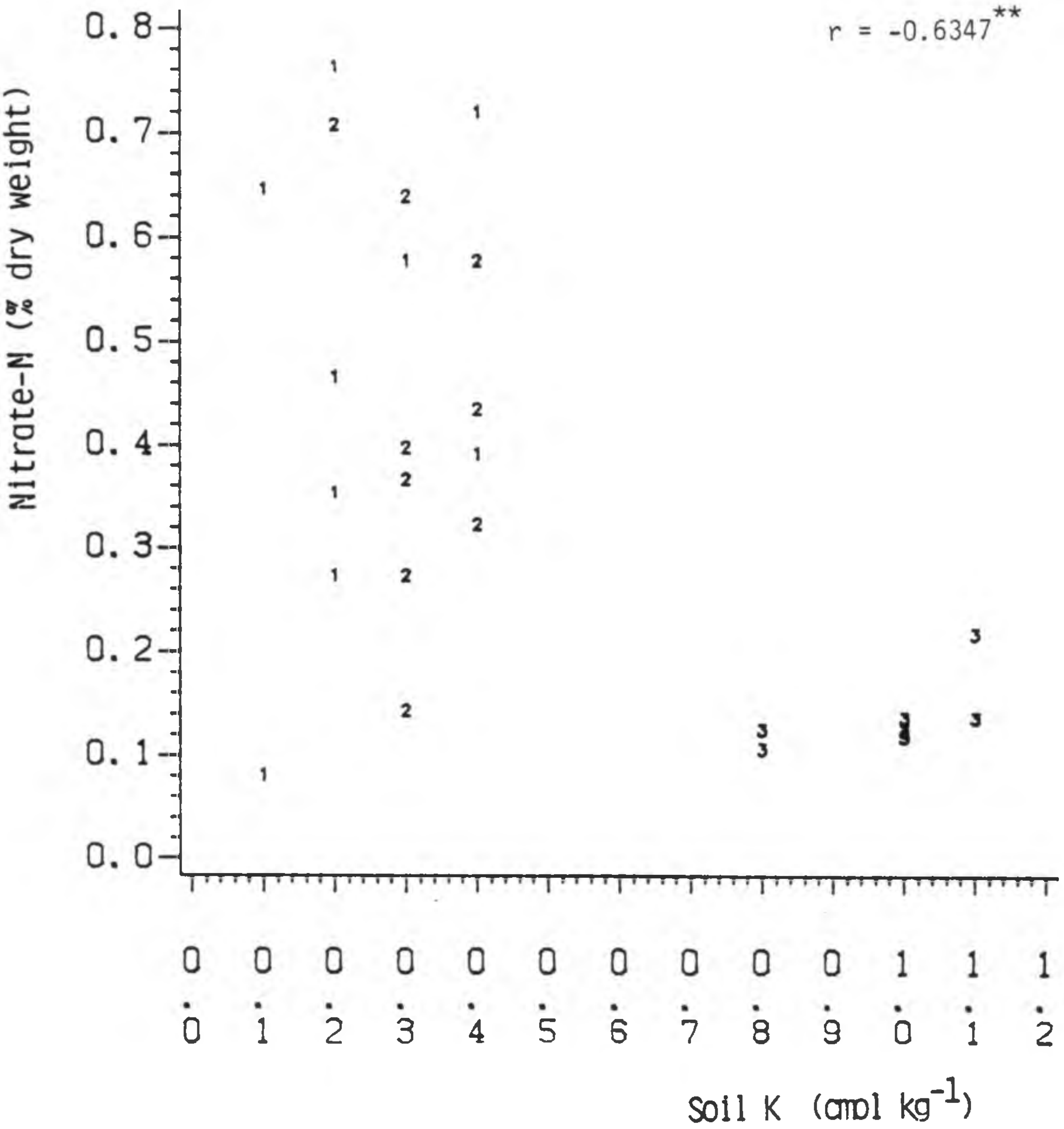


Figure 4.30. Relationship between tissue nitrate-N concentration of amaranth and soil K from non-irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

Table 4.46

Multiple regression equation for nitrate-N concentration in amaranth from irrigated plots of three experimental sites

Varaible*	Regression coefficient	Standard error	t	Probability > |t|
Intercept	-31.6711	10.4777	-3.023	0.0065
AIR2SQ	0.1377	0.0498	2.763	0.0116
NLEVEL	0.0603	0.0169	3.559	0.0019
SOLTN	27.4725	9.9755	2.754	0.0119

Model r^2 = 0.6595

Model Adj. r^2 = 0.6108

* AIR2SQ = Square of minimum temperature

NLEVEL = Fertilizer N rate

SOLTN = Soil N concentration.

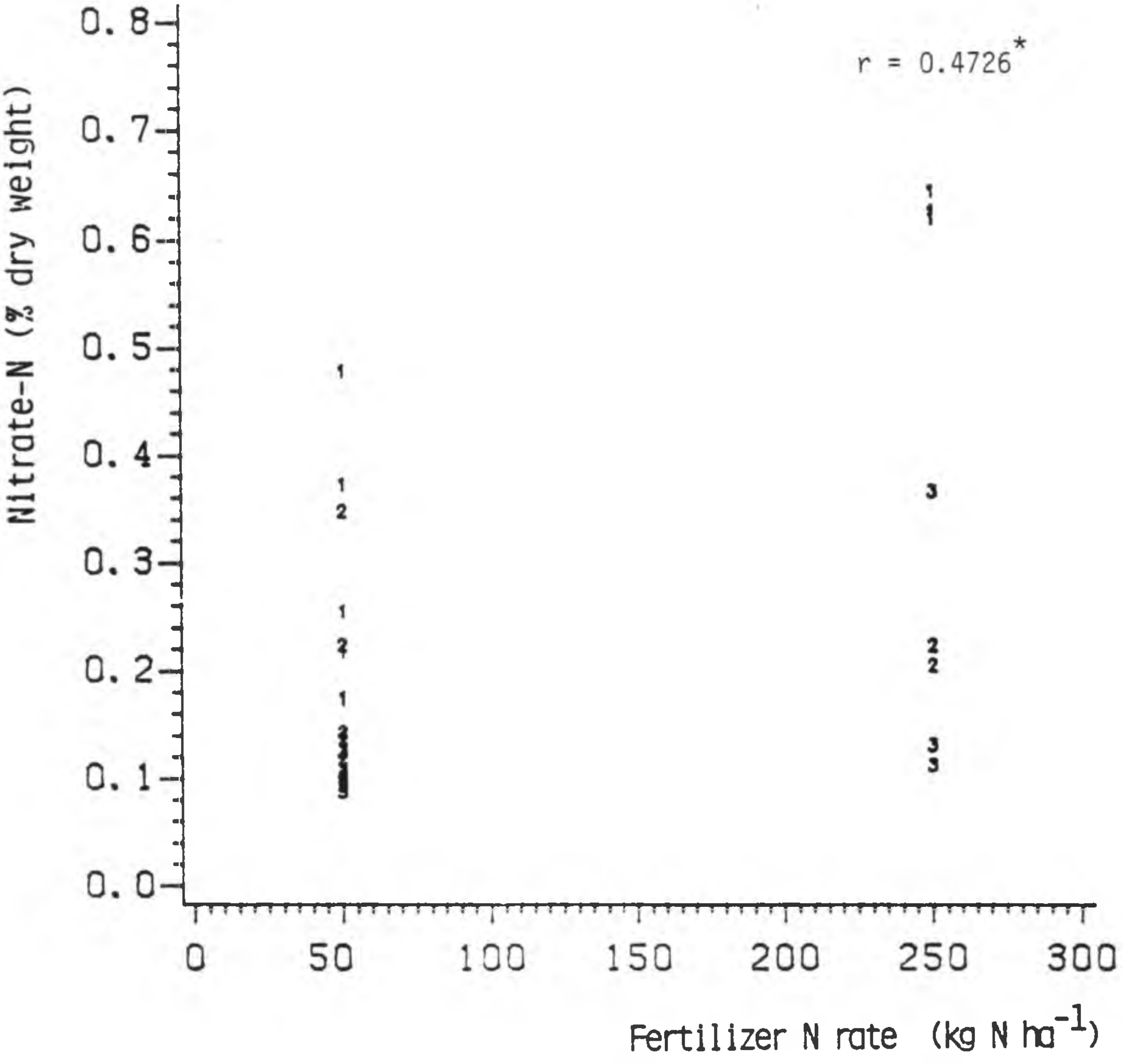


Figure 4.31. Relationship between tissue nitrate-N concentration of amaranth and fertilizer N rate from irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

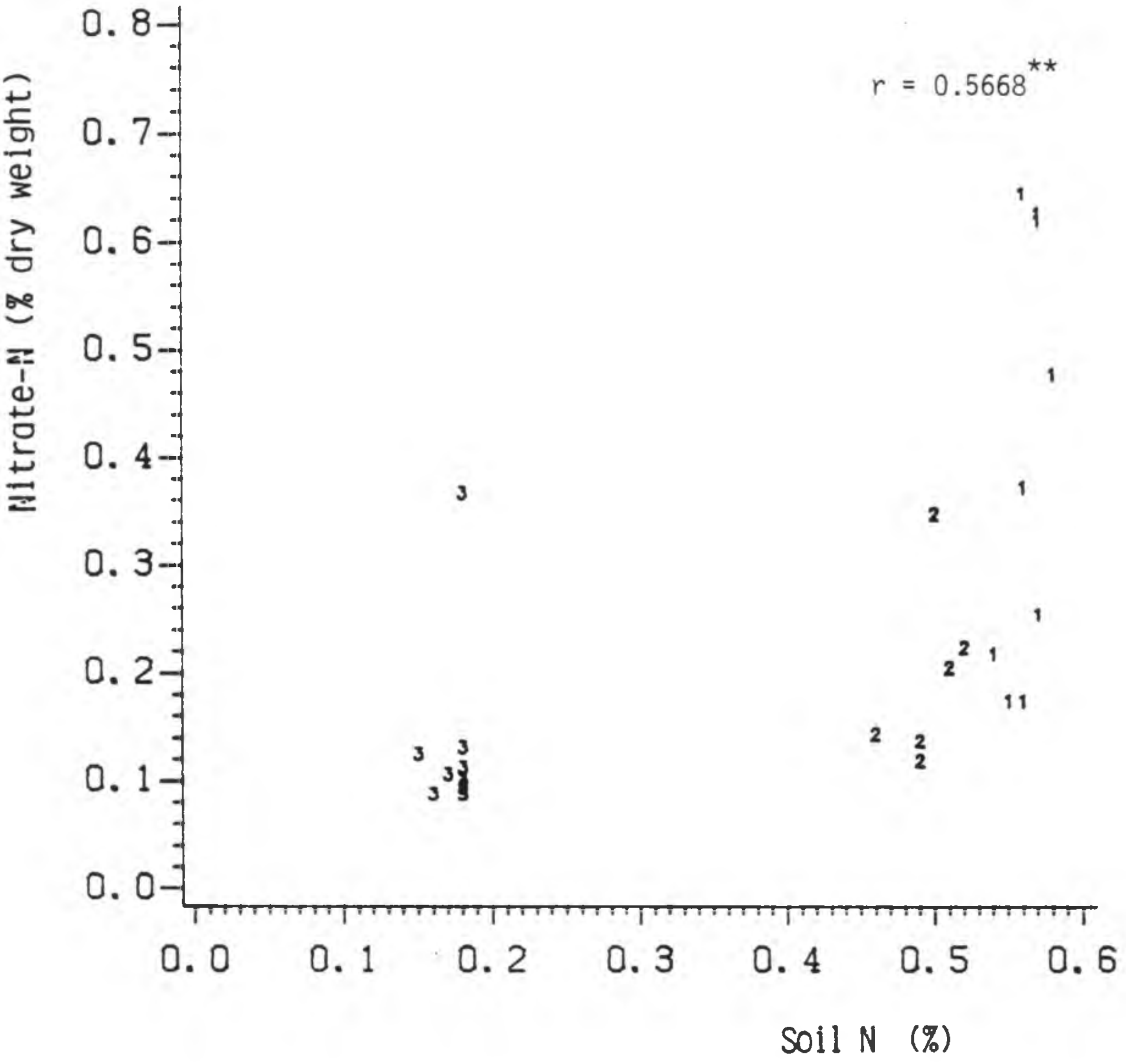


Figure 4.32. Relationship between tissue nitrate-N concentration of amaranth and soil N from irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

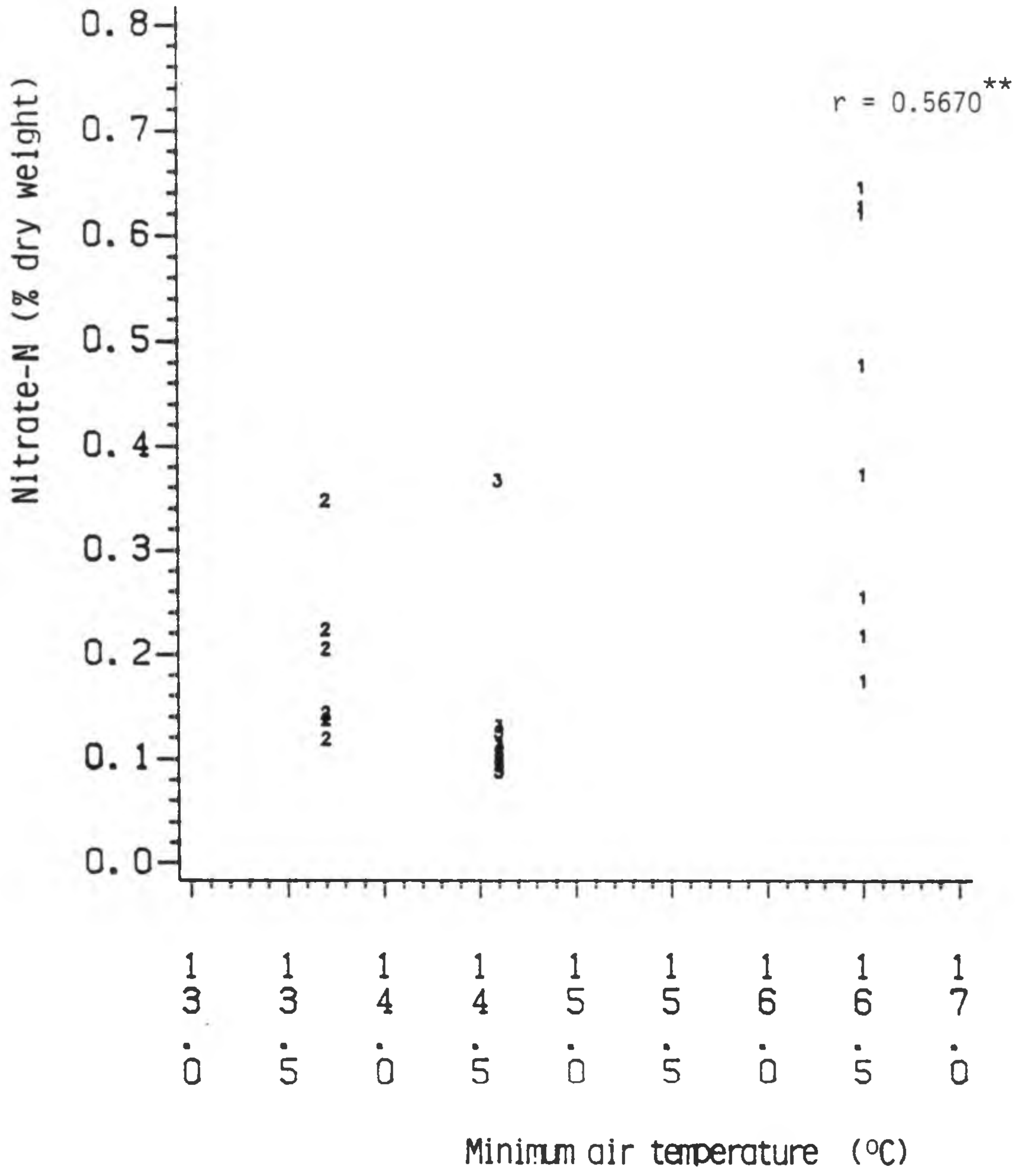


Figure 4.33. Relationship between tissue nitrate-N concentration of amaranth and minimum air temperature from irrigated plots of experiments at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

4.3.1 Forms and content of oxalate in cassava leaves

The significant positive correlations between concentrations of total and insoluble oxalate and tissue Ca and Mg suggest that oxalate in cassava leaves was in the form of Ca oxalate or Mg oxalate or both. However, the fact that total and insoluble oxalate had significant positive correlations only with Ca in the insoluble fraction (Table 4.47, Figures 4.34, 4.35) and not with Mg (Table 4.47) suggests that oxalate in cassava was mostly in the form of Ca oxalate. Another suggestion of the dominance of Ca oxalate over Mg oxalate is that the sum of Ca and Mg was not as well correlated with oxalates as Ca alone (Table 4.47).

Soluble oxalate was detected in only one sample from the Molokai, non-irrigated plot which had a soluble oxalate content of 6.5 cmol kg^{-1} dry weight. The insoluble oxalate concentration, from Molokai and Iole plants was consistently lower than total oxalate concentration (Appendix E) and consequently, the difference between the two was taken as the soluble oxalate concentration (Table 4.48, Appendix E). Molokai plants had a relatively higher content of soluble oxalate than the plants from the other sites, while Waipio plants had virtually no soluble oxalate (Table 4.48, Appendix E). It cannot be stated for certain from this study what form of soluble oxalate occurred in cassava leaves. It probably was Mg or K oxalate or both. Nevertheless, the fact that Waipio plants had significantly higher tissue Ca concentration and lower tissue K concentration than the plants from the other three sites (Table 4.49) probably accounts for the absence of soluble oxalate

Table 4.47

Correlation between oxalates and various cations in cassava leaves

	Correlation coefficients* (Probability > |r|)	
Element	Total oxalate	Insoluble oxalate
Tissue Ca	0.5883 (0.0064)	0.6444 (0.0022)
Mg	0.4222 (0.0637)	0.5898 (0.0062)
K	-0.1998 (0.3984)	-0.4482 (0.0475)
Na	-0.3700 (0.1083)	-0.2642 (0.2604)
Insoluble fraction Ca	0.6239 (0.0033)	0.7751 (0.0001)
Mg	-0.0141 (0.9529)	0.1935 (0.4138)
K	-0.3167 (0.1737)	-0.3785 (0.0998)
Na	0.7414 (0.0002)	0.7415 (0.0002)
Ca+Mg	0.5835 (0.0069)	0.7472 (0.0001)

* Number of observations = 20.

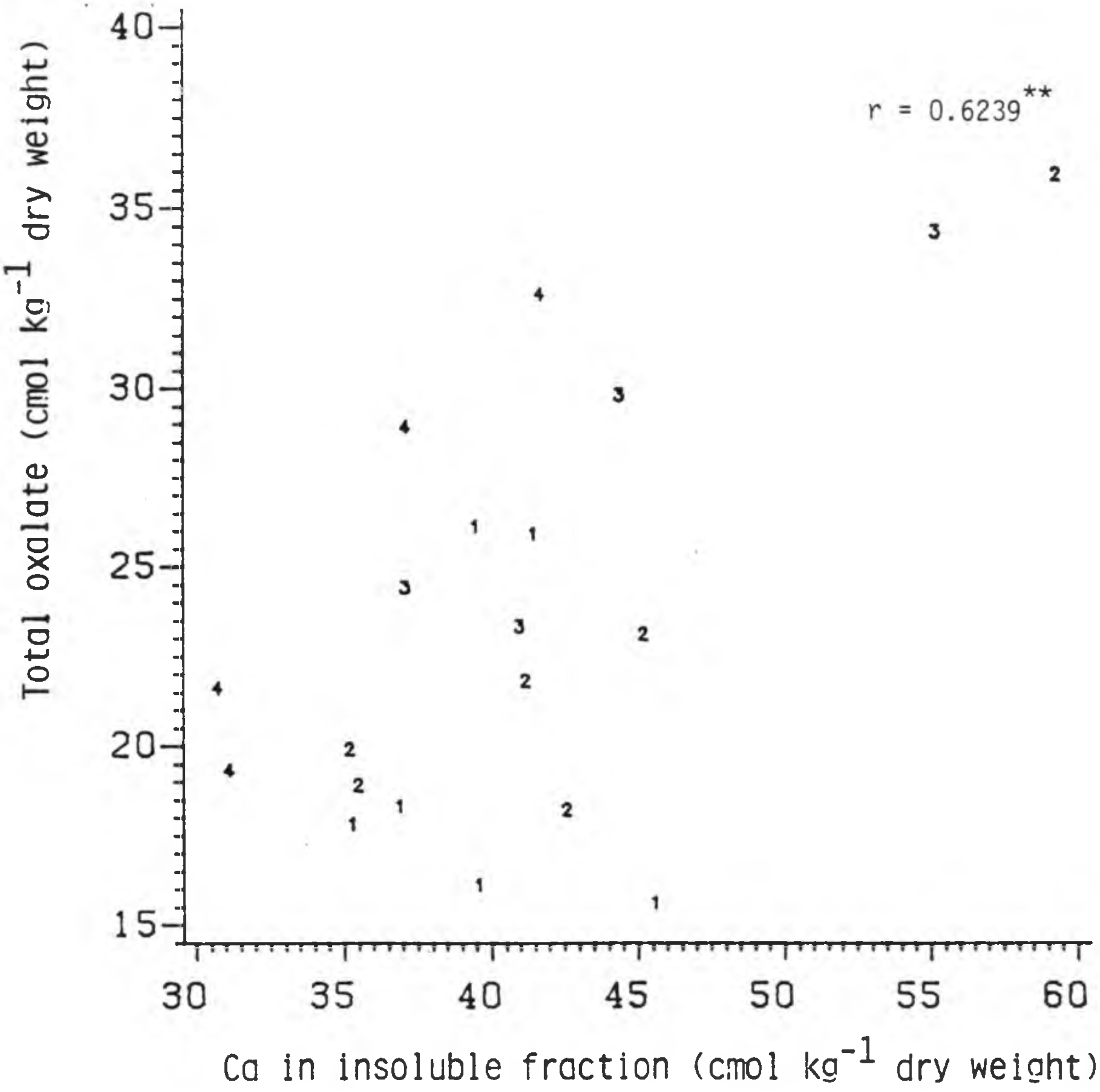


Figure 4.34. Relationship between total oxalate and Ca in the extract of insoluble oxalate fraction of leaf tissue of cassava grown at four sites (1=Kukaiau, 2=Iole, 3=Waipio).

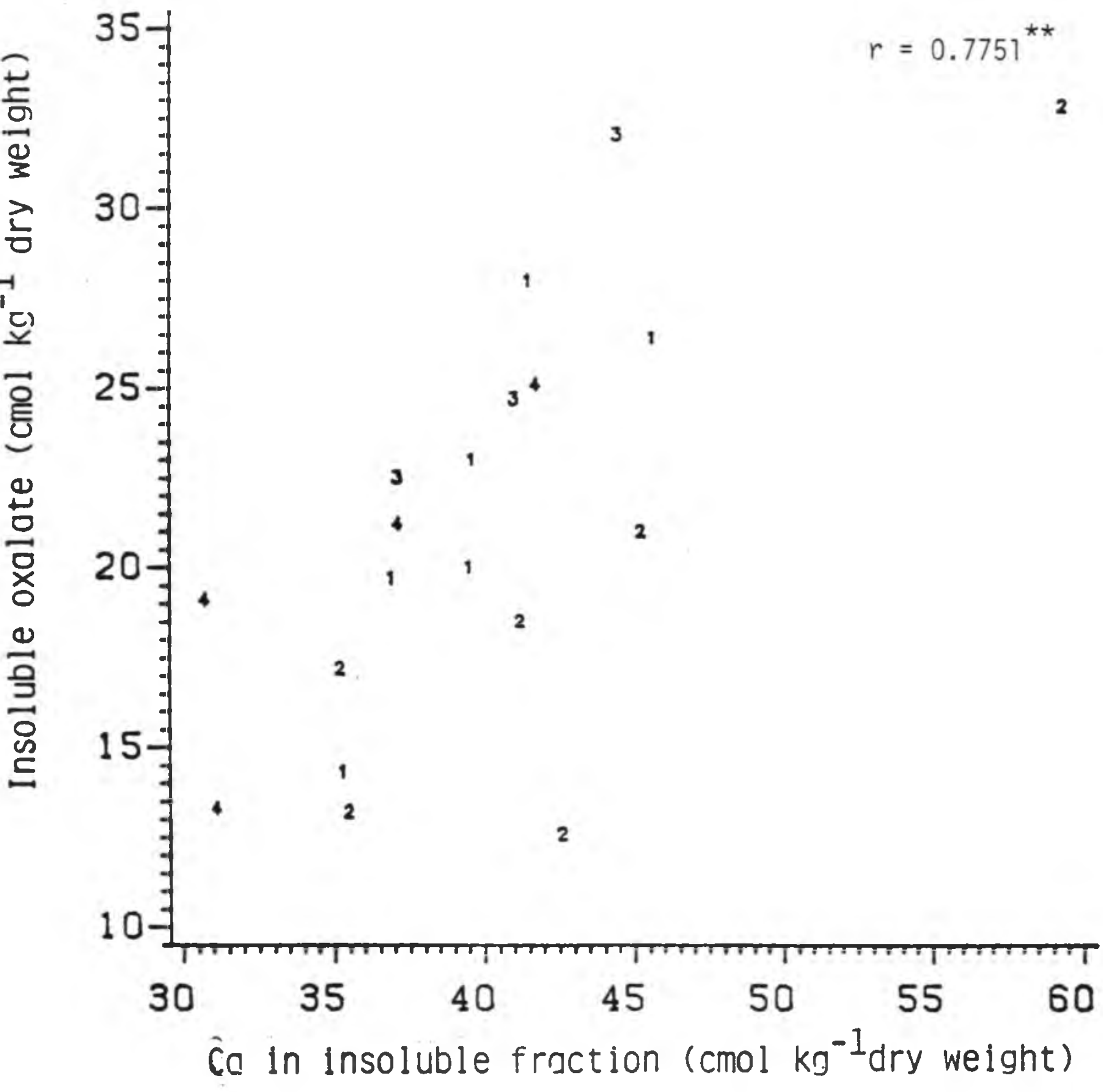


Figure 4.35. Relationship between insoluble oxalate and Ca in the extract of insoluble oxalate fraction of leaf tissue of cassava grown at four sites (1=Kukaiau, 2=Iole, 3=Waipio).

Table 4.48

Oxalate concentration in cassava leaf tissue of plant grown at four different sites

Site	Total oxalate	Insoluble oxalate	Soluble oxalate[d]
	(cmol kg^{-1} dry weight)		
Molokai	25.6 A[b] (1.2)[c]	19.7 B[b]	5.9
Waipio	28.0[a] A (1.3)	29.4 A	-
Iole	23.0 A (1.0)	19.2 B	3.8
Kukaiau	20.0[a] A (0.9)	21.9 AB	-

[a]Pair comparison using LSD show that the two means are significantly different (Probability > |t| = 0.0464).

[b]Means in the same column followed by the same capital letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

[c]Oxalate concentration in the unit of % on a dry weight basis.

[d]Soluble oxalate was obtained by subtracting insoluble oxalate from total oxalate.

in Waipio plants and that if soluble oxalate did occur it would do so in the form of K oxalate.

The content of total oxalate in cassava leaves ranges from 0.9-1.3% on a dry weight basis (Table 4.48). This range was considerably less than that in amaranth.

4.3.2 Chemical compositions of plants grown at different sites

Waipio plants had higher concentrations of total and insoluble oxalates than the plants from the other sites (Table 4.48). For Waipio plants, the results showed that all oxalate was in the forms of insoluble oxalate while some soluble oxalate occurred in plants from Molokai and Iole (Table 4.48). The higher Ca concentration in Waipio plants (Table 4.49) probably led to the higher Ca oxalate concentration in these plants. The relatively higher K concentrations in plants from the Molokai and Iole sites (Table 4.49) probably led to the occurrence of small quantities of soluble oxalate.

It appears that the oxalate form was determined by the dominant cations in the plants. Ca was the dominant cation in plants from Waipio (Table 4.49), which probably resulted in Ca oxalate being the primary form of oxalate. Molokai and Iole plants had about equal concentrations of Ca and K which may have promoted the formation of K oxalate although Ca oxalate was still dominant.

Relationship between oxalate concentrations and cation excess

Oxalate constituted only 18.6-25.9% of the cation excess in cassava leaves (Table 4.51). It is probable that oxalate was not the dominant organic acid in cassava. This is different from amaranth in which more than 60% of cation excess was accounted for by oxalate.

Table 4.49

Ionic concentrations and cation excess contents in cassava grown at four experimental sites

Site	Ca	Mg	K	Na	SC[a]	P	S	NO_3	Cl	SA[b]	C-A
	(cmol kg^{-1} dry weight)										
Molokai	53.6 B[c]	18.8 B[c]	49.7 A[c]	1.5 A[c]	123.6 A[c]	3.6 B[c]	5.2 B[c]	7.7 A[c]	5.8 A[c]	22.2 A[c]	101.4 A[c]
	(1.1)[d]	(0.2)	(1.8)	(0.03		(0.3)	(0.2)		(0.20)		
Waipio	63.9 A	22.7 A	42.7 B	1.2 C	130.2 A	3.9 B	4.8 C	7.8 A	5.8 A	22.2 A	108.1 A
	(1.3)	(0.3)	(1.7)	(0.03)		(0.4)	(0.2)		(0.19)		
Iole	54.4 AB	18.9 B	50.2 A	1.3 BC	124.9 A	5.6 A	5.5 A	2.9 C	4.7 B	18.6 B	106.3 A
	(1.1)	(0.2)	(2.0)	(0.03)		(0.5)	(0.3)		(0.17)		
Kukaiau	55.8 AB	18.6 B	50.5 A	1.6 A	126.5 A	4.2 B	5.2 B	4.9 B	4.9 AB	19.2 B	107.4 A
	(1.1)	(0.2)	(2.0)	(0.04)		(0.4)	(0.2)		(0.17)		

[a]Sum of cations

[b]Sum of anions

[c]Means of each ion with the same capital letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

[d]Ionic concentrations in the unit of % on a dry weight basis.

Table 4.50

Insoluble oxalate and calcium concentrations in cassava grown at four sites

Site	Insoluble oxalate	Tissue Ca	Ca in the form of Ca oxalate
	(cmol kg^{-1} dry weight)		(% tissue Ca)
Molokai	19.7	53.6	37
Waipio	29.4	63.6	46
Iole	19.2	54.4	35
Kukaiau	21.9	55.8	39

Total oxalate was positively correlated with cation excess (Figure 4.36). Oxalate exhibited a higher positive correlation with Ca than with cation excess, therefore, it can be said that oxalate was more closely related with Ca concentration than with cation excess. Since oxalate was probably not the primary organic acid in cassava, the lack of a significant response to cation excess was not surprising. It might very well be that in cassava, total organic acid responded to cation excess, whereas, oxalate responded to Ca. The literature is not consistent with regard to the relationship between oxalate synthesis and Ca absorption. Olsen (1939) and Rasmussen and Smith (1961) reported a positive relationship between Ca and oxalic acid in some plants. On the other hand, Osmond (1967) found no relationship between oxalate synthesis and Ca absorption in *Atriplex*. He also found that oxalate content correlated with cation content rather than Ca alone.

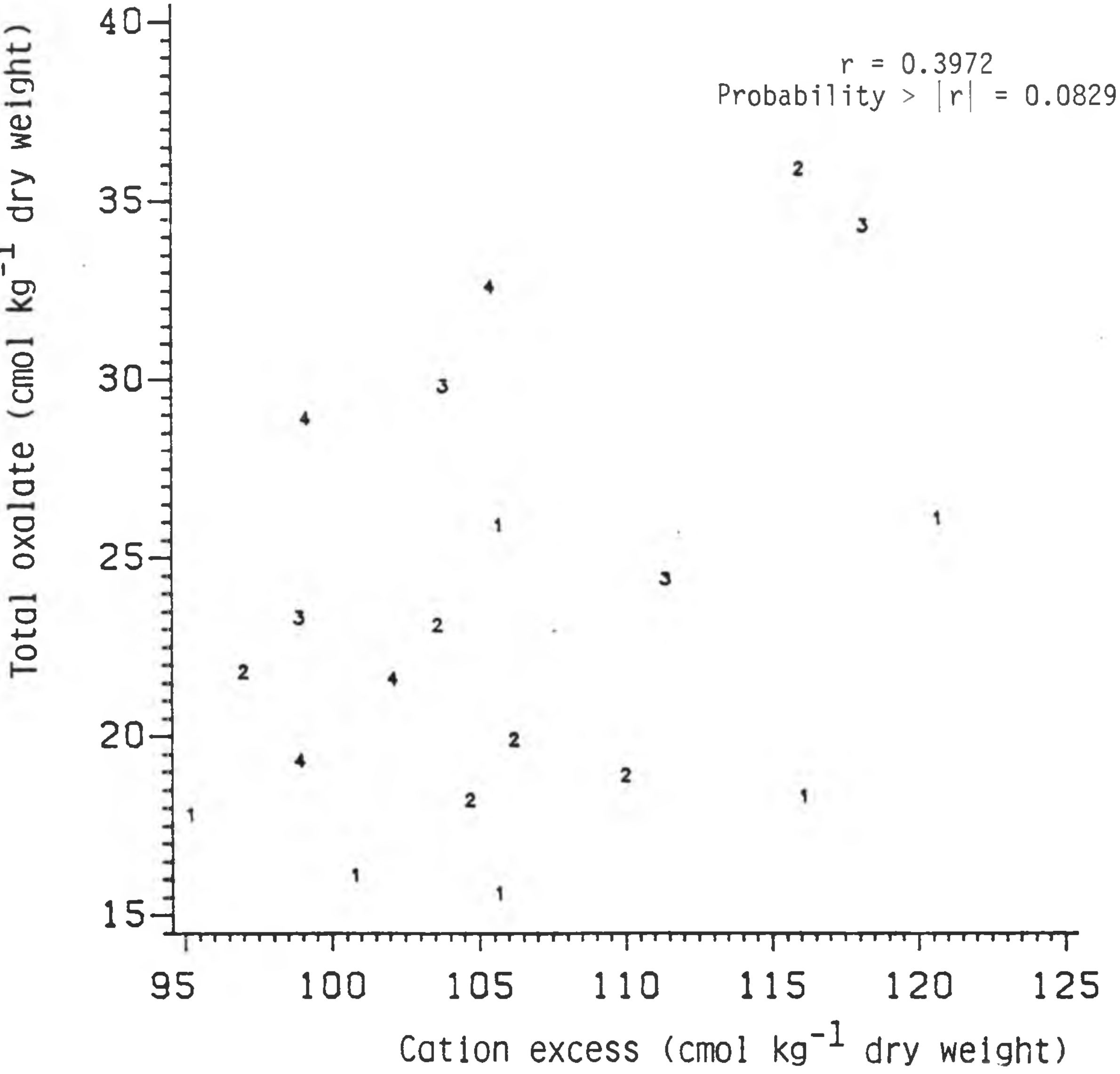


Figure 4.36. Relationship between total oxalate concentration and cation excess in leaf tissue of cassava grown at four sites
(1=Kukaiau, 2=Iole, 3=Waipio).

Table 4.51

Oxalate content as percentage of cation excess (C-A) in cassava leaves

Site	Total oxalate	Cation excess	Total oxalate (% C-A)
	(cmol kg^{-1} dry weight)		
Molokai	25.6	101.4	25.2
Waipio	28.0	108.1	25.9
Iole	23.0	106.3	21.6
Kukaiau	20.0	107.4	18.6

Total N and nitrate-N concentrations and crude protein content

Higher total N and crude protein contents occurred in plants grown at the Hydric Dystrandept sites than at the Tropeptic Eutrustox sites (Table 4.52). This also occurred in amaranth plants and can be attributed to the higher soil N content in Hydric Dystrandept soils. On the other hand, nitrate-N was significantly higher in plants grown in the Tropeptic Eutrustox than in plants from the Hydric Dystrandept sites. The reason behind the higher nitrate-N in Tropeptic Eutrustox plants despite the lower soil N may be due to the climatic effects on nitrate assimilation. Nitrate concentration was positively correlated with air and soil temperatures (Table 4.57). High temperature can decrease the nitrate reductase activity which results in the accumulation of nitrate (Cantliffe, 1972a). The different results for nitrate-N between amaranth and cassava may also be caused by differences in rooting depth and length of growing period. Cassava roots permeate

Table 4.52

Total N, nitrate-N and crude protein contents in the leaves of cassava grown at four sites

Site	Total N*	Nitrate-N*	Crude protein*
	(% dry weight)		
Molokai	4.60 B	0.11 A	28.8 B
Waipio	4.29 C	0.11 A	26.8 C
Iole	5.18 A	0.04 C	32.4 A
Kukaiau	4.72 B	0.07 B	29.5 B

* Means in the same column followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

a larger volume of soil for a longer period of time than do amaranth roots. Nitrate-N found in cassava leaves in this study is not considered high and did not present a health hazard.

Crude protein content of cassava leaves was 26.8-32.4% on a dry weight basis. This is in the high range of protein content reported in the literature (Rogers and Milner, 1963).

4.3.3 Effects of irrigation on chemical composition of plants grown at Molokai and Waipio sites

Significantly higher total and insoluble oxalates were in non-irrigated plants at Molokai but not at Waipio (Table 4.53). Both Molokai and Waipio are considered dry sites, but Molokai was even drier than Waipio as shown by the nearly two-fold less precipitation received at Molokai (Table 3.21).

Total N concentration was significantly lower in non-irrigated plants at Molokai (Table 4.54). Nitrate-N concentrations were not affected by irrigation.

Table 4.53

Effect of irrigation on oxalate concentration of taro grown at Molokai and Waipio

	Site			
	Molokai		Waipio	
	Total oxalate	Insoluble oxalate	Total oxalate	Insoluble oxalate
Irrigation*	cmol kg^{-1} dry weight			
NI	45.9	39.5	31.8	25.6
I	25.6	19.7	28.0	29.4
Probability > |F|	0.0426	0.0030	0.3792	0.4516

* NI = Non-irrigated, I = Irrigated

4.3.4. Influence of plant, soil, and climatic factors on oxalate and nitrate concentrations

Insoluble oxalate concentrations were negatively correlated with total N but positively correlated with nitrate-N (Table 4.55). The negative relationship between oxalates and total N was rather surprising because nitrogen metabolism usually promotes the synthesis of oxalate. Total N was negatively correlated with tissue Ca (Figure 4.37). This

Table 4.54

Effect of irrigation on total N and nitrate-N concentrations in taro grown at Molokai and Waipio

	Site			
	Molokai		Waipio	
	Total N	Nitrate-N	Total N	Nitrate-N
Irrigation*	% dry weight			
NI	4.08	0.11	4.30	0.10
I	4.60	0.11	4.29	0.11
Probability > |F|	0.0045	0.7718	0.9213	0.0887

* NI = Non-irrigated, I = Irrigated

Table 4.55

Correlation between oxalates and total N and nitrate-N in cassava leaves grown at four sites

	Correlation coefficient* (Probability > |r|)	
Oxalate	Total N	Nitrate-N
Total	-0.4129 (0.0704)	0.4317 (0.0574)
Insoluble	-0.6393 (0.0024)	0.4082 (0.0740)

*Number of observations = 20

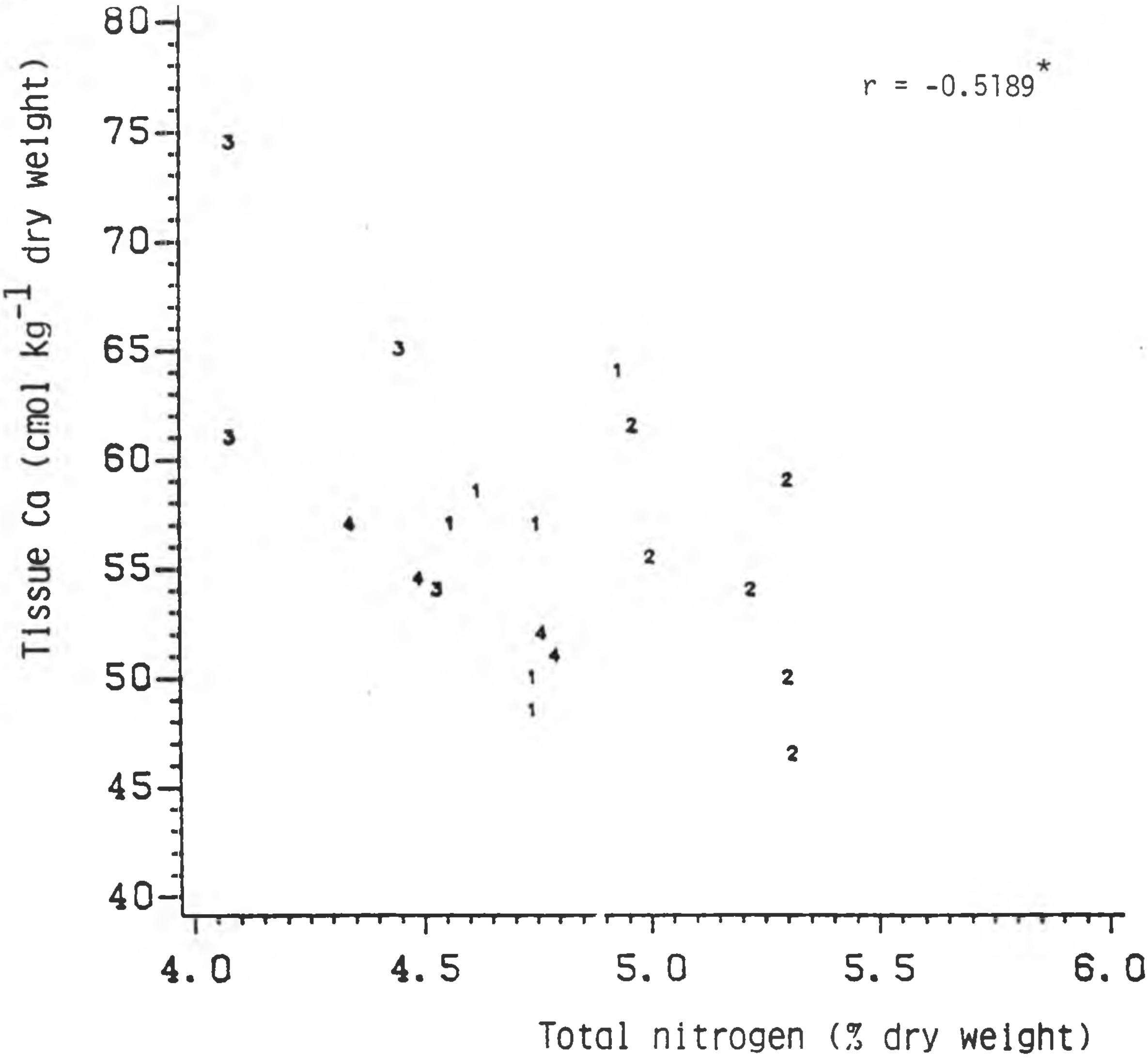


Figure 4.37. Relationship between Ca and total N concentration in leaf tissue of cassava grown at four experimental sites (1=Kukaiau, 2=Iole, 3=Waipio).

suggests that total N and Ca are also correlated and therefore, the relationship between total N and oxalates may not be a causal one.

Oxalate and nitrate were positively correlated with soil cations while nitrate was negatively correlated with soil P (Table 4.56). The uptake of cations can increase the cation excess in plants which, in turn, leads to the synthesis of organic acid.

Table 4.56

Correlation between oxalate in cassava and soil variables from four sites

Soil variables	Correlation coefficients* (Probability > |r|)		
	Total oxalate	Insoluble oxalate	Nitrate
Soil Ca	ns**	ns	ns
Mg	0.4727 (0.0353)	0.4400 (0.0522)	0.6243 (0.0033)
K	0.4743 (0.0346)	ns	0.7148 (0.0004)
Na	0.4528 (0.0450)	ns	0.8190 (0.0001)
P	ns	ns	-0.4745 (0.0345)

* Number of observations = 20
** ns = non-significant

The positive correlations between temperature and oxalates (Table 4.57) in cassava were different from the relationship found in amaranth. Kitchen et al. (1964b) postulated that in spinach, oxalate

Table 4.57

Correlation between oxalate and nitrate in cassava
with some climatic variables from four sites

Climatic variable	Correlation coefficient* (Probability > |r|)		
	Total oxalate	Insoluble oxalate	Nitrate-N
Average air temperature	ns**	ns	0.8510 (0.0001)
Average relative humidity	ns	-0.4581 (0.0422)	ns
Average topsoil temperature	ns	0.4701 (0.0365)	0.7362 (0.0002)
Average subsoil temperature	0.4626 (0.0400)	0.4481 (0.0475)	0.7198 (0.0003)
Rainfall	-0.4583 (0.0421)	ns	-0.6953 (0.0007)
Radiation	ns	ns	0.8485 (0.0001)
Wind speed	ns	ns	ns

* Number of observations = 20
** ns = non-significant

was used as a substrate for respiration at high temperature. The positive correlations of nitrate with temperature and radiation were also found in amaranth. Cantliffe (1972a) and Maynard et al. (1976) found similar relations in other plants.

4.4 Response of taro to environmental factors

As in the case with the section on cassava, this section emphasizes the results concerning the effects of environmental factors on nutrient and antinutrient contents of taro leaves.

4.4.1 Forms of oxalate in taro

Taro contained both soluble and insoluble oxalates in contrast to cassava where most oxalate was in the insoluble form. The positive correlation between insoluble oxalate and Ca (Table 4.58, Figure 4.38) suggests that insoluble oxalate was primarily Ca oxalate. Moreover, the higher correlation of Ca plus Mg concentrations with insoluble oxalate (Table 4.58, Figure 4.39) suggests that a part of the insoluble oxalate was in the form of Mg oxalate.

There was a positive correlation between both tissue K and K in the soluble oxalate fraction with soluble oxalate (Table 4.58, Figure 4.40). This suggests that the soluble oxalate was primarily K oxalate. Mg oxalate probably constituted a significant part of soluble oxalate as suggested by high correlation where Mg was also considered, r = 0.7898 (Table 4.58). The correlation between K+Mg in the soluble fraction and soluble oxalate was highly significant (Figure 4.41) suggesting that K and Mg oxalate were important constituents in taro.

Table 4.58

Correlation between oxalates and mineral concentration in taro leaves

Element		Correlation coefficient* (Probability > |r|)		
		Soluble oxalate	Insoluble oxalate	Soluble+Insoluble oxalate
Tissue	Ca	-0.7881 (0.0001)	0.3282 (0.0053)	ns
	Mg	ns**	ns	0.3435 (0.0323)
	K	0.6931 (0.0001)	ns	0.3412 (0.0335)
	Na	-0.5675 (0.0002)	0.3526 (0.0277)	ns
Soluble fraction	Ca	-0.6012 (0.0001)	ns	ns
	Mg	0.4531 (0.0038)	ns	0.4240 (0.0071)
	K	0.6712 (0.0001)	ns	ns
	Na	ns	ns	ns
	K+Mg	0.7898 (0.0001)	ns	-
Insoluble fraction	Ca	-0.7637 (0.0001)	0.4755 (0.0022)	ns
	Mg	ns	0.3741 (0.0190)	0.4652 (0.0028)
	K	0.3415 (0.0334)	-0.3201 (0.0470)	ns
	Na	-0.6858 (0.0001)	0.3360 (0.0365)	ns
	Ca+Mg	-0.7270 (0.0001)	0.5036 (0.0001)	ns

* Number of observations = 42

** ns = Non-significant.

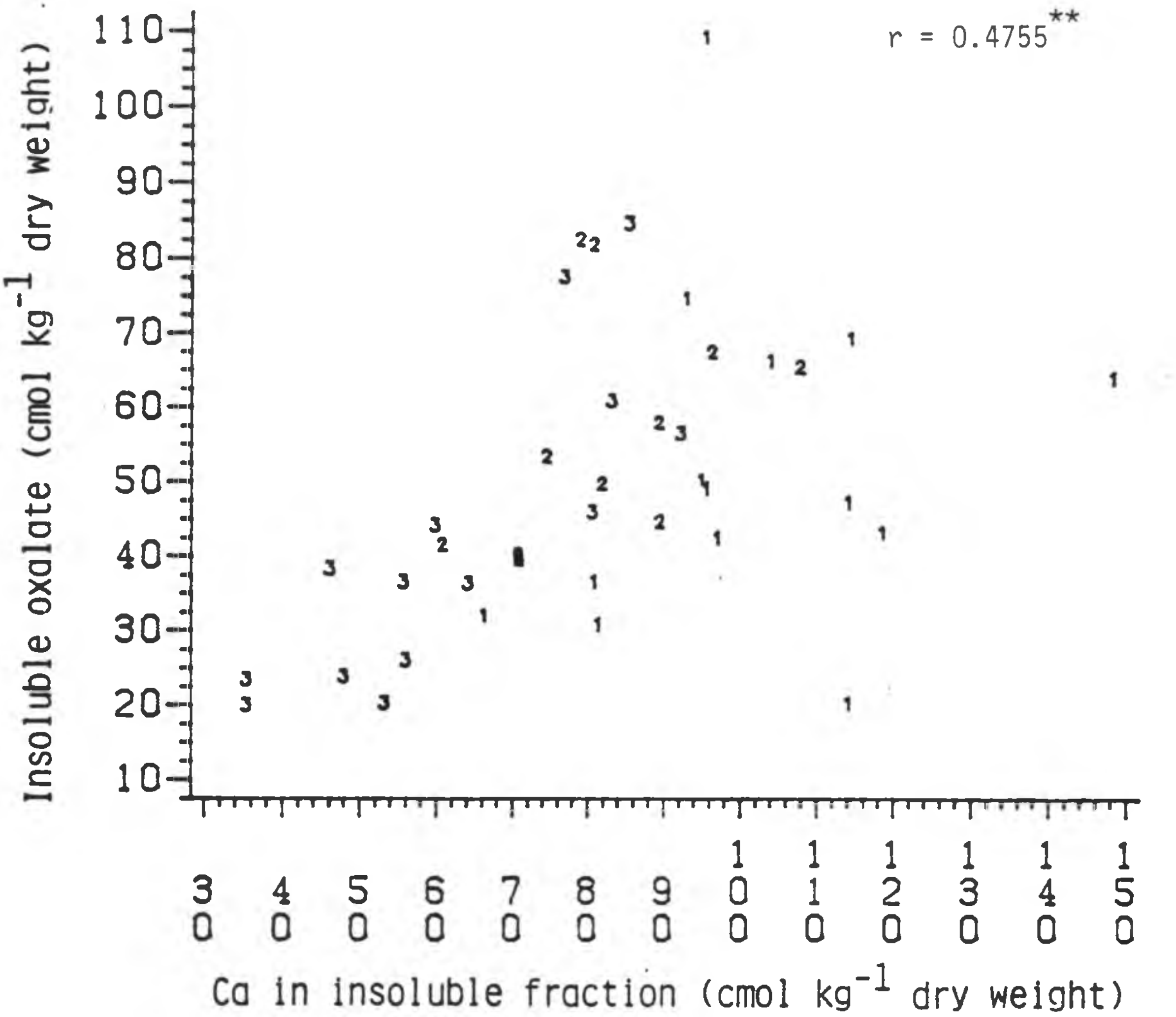


Figure 4.38. Relationship between insoluble oxalate and calcium in the extract of insoluble oxalate fraction of leaf tissue of taro grown at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

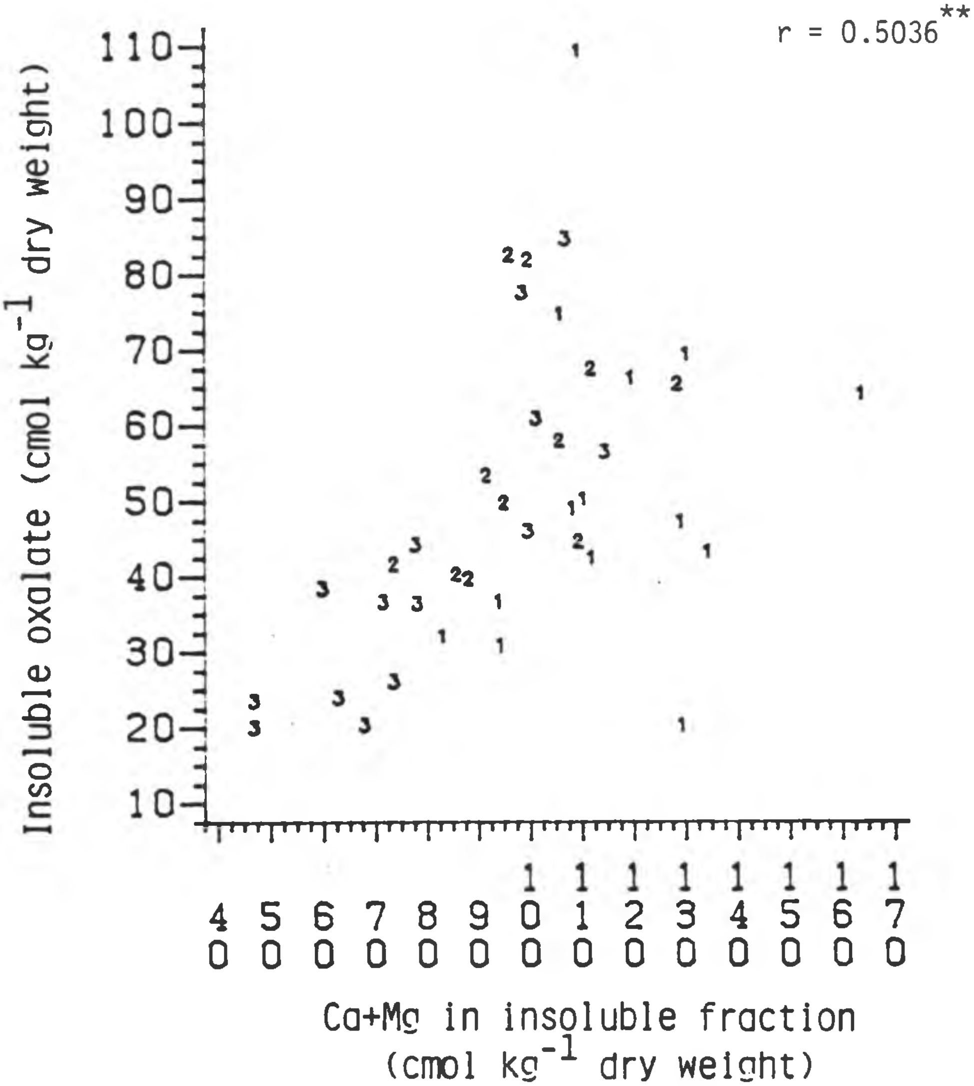


Figure 4.39. Relationship between insoluble oxalate and the sum of calcium and magnesium concentration in the extract of insoluble oxalate fraction of leaf tissue of taro grown at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

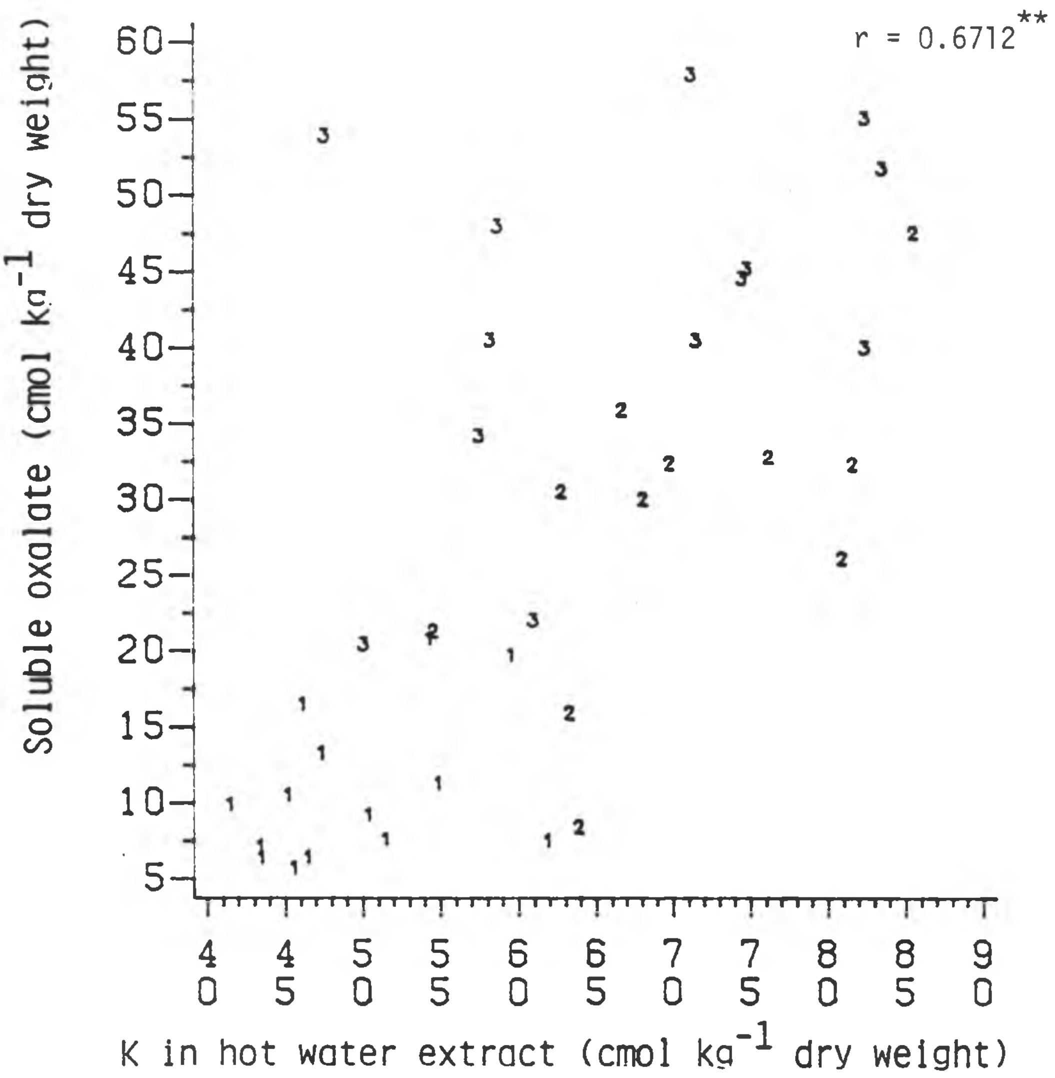


Figure 4.40. Relationship between soluble oxalate and potassium concentration in the extract of soluble oxalate fraction (hot water extract) of leaf tissue of taro grown at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

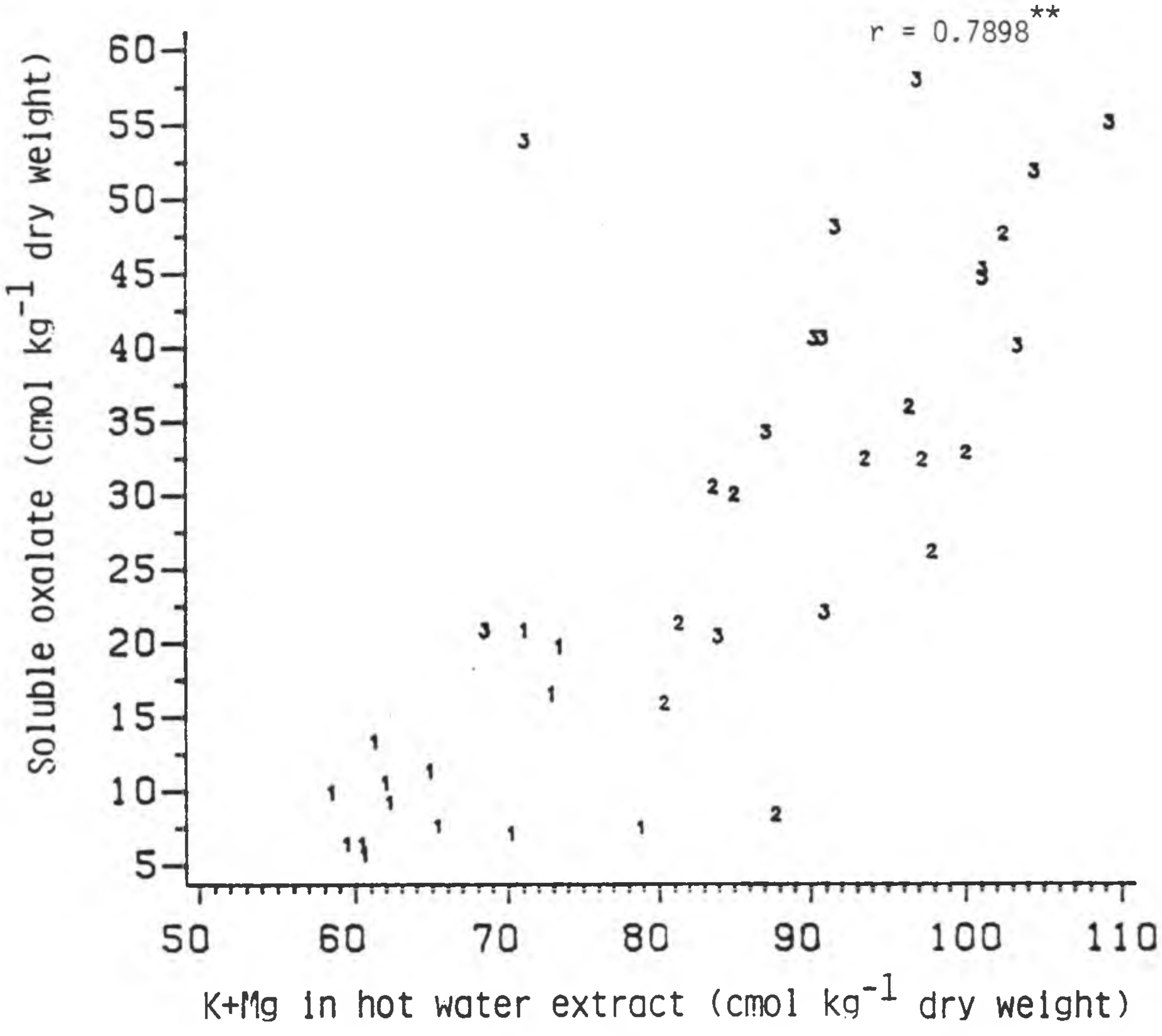


Figure 4.41. Relationship between soluble oxalate and the sum of potassium and magnesium concentration in the extract of soluble oxalate fraction (hot water extract) of leaf tissue of taro grown at three sites (1=Kukaiau, 2=Iole, 3=Waipio).

The analysis of mineral concentrations, including Ca, Mg, K and Na in the soluble and insoluble fraction also shows that the dominant cation in the soluble fraction was K while Ca appears to dominate in the insoluble fraction (Table 4.59). Little Ca was found in the soluble fraction and little K was found in the insoluble fraction.

Ca oxalate crystals are known to be plentiful in taro leaves (Sunell and Arditti, 1983). These crystals have been implicated in the irritant quality of taro. Sunell and Arditti (1983) suggested that Ca oxalate plays a role in Ca balance within the plant. Sunell and Healey (1979) reported that Ca oxalate in taro was not metabolically inactive because crystal numbers and density changed during plant development. The finding of soluble oxalate in taro implies that Ca from other foods can be bound and rendered unavailable.

4.4.2 Comparison of chemical composition of plants grown at different sites

Significantly higher soluble oxalate was found in plants from the Tropeptic Eutrustox soil at the Waipio site than in plants grown in the Hydric Dystrandept soils at Kukaiau and Iole (Table 4.60). Furthermore for soils of the same family of Hydric Dystrandepts, plants from Iole had significantly higher soluble oxalate than plants from Kukaiau (Table 4.60). Plants grown at Waipio and Iole had significantly higher tissue K and Mg concentrations than did plants at Kukaiau (Table 4.61). Higher soluble oxalate was also found in Waipio and Iole plants. Although Iole plants had almost equal concentrations of tissue K as the Waipio plants, they had significantly higher tissue Ca. This was

Table 4.59

Mineral concentrations in the soluble and insoluble fraction of extracts of oxalate in taro grown at three sites

Site	cmol kg^{-1} dry weight									
	Soluble fraction					Insoluble fraction				
	Oxalate	Ca	Mg	K	Na	Oxalate	Ca	Mg	K	Na
Kukaiau	10.9	2.6	16.4	49.4	0.22	52.5	101.4	14.6	2.1	0.90
Iole	28.5	2.3	20.8	71.2	0.31	56.7	78.6	16.3	2.4	0.84
Waipio	41.1	1.5	27.3	65.0	0.25	42.4	62.3	16.7	2.3	0.62

Table 4.60

Oxalate concentrations of taro leaves grown at three different experimental sites

Site	cmol kg^{-1} dry weight		
	Soluble* oxalate	Insoluble* oxalate	Soluble + Insoluble* oxalate
Kukaiau	10.9 C	52.5 A[a]	63.4 B
Iole	28.5 B	56.7 A[b]	85.2 A
Waipio	41.1 A	42.4 A[c]	83.5 A

* Means in the same column followed by the same capital letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

[a] 12.7 mg/g FW

[b] 13.7 mg/g FW

[c] 10.3 mg/g FW

probably the reason for the lower soluble oxalate in plants grown at Iole than at Waipio.

Plants from the Hydric Dystrandept soils contained higher insoluble oxalate than plants grown in the Tropeptic Eutrustox soil. This was associated with the significantly higher tissue Ca in plants from the Hydric Dystrandepts (Table 4.61).

Table 4.60 also shows that while the insoluble oxalate did not vary with site the soluble fraction did. Tissue Ca was higher in plants from Kukaiau than from Iole and Waipio while tissue K was higher in Iole and Waipio than in plants from Kukaiau (Table 4.61). This probably led to the higher proportion of insoluble oxalate and a lower proportion

Table 4.61

Ionic concentrations and cation excess in taro leaves grown in three experimental sites

Site	cmol kg^{-1} dry weight (% dry weight)										
	Ca	Mg	K	Na	SC[a]	P	S	NO_3	Cl	SA[b]	C-A
Kukaiau	131.7 A[c] (2.6)[d]	33.3 C[c] (0.4)	90.6 B[c] (3.5)	1.1 A[c] (0.03)	256.8 A[c]	3.2 C[c] (0.31)	5.9 A[c] (0.3)	7.1 A[c]	36.6 A[c] (1.3)	52.7 A[c]	204.1 A[c]
Iole	110.3 B (2.2)	43.7 B (0.5)	111.1 A (4.3)	1.1 A (0.03)	266.2 A	3.8 B (0.37)	5.6 A (0.3)	7.2 A	28.9 B (1.0)	45.5 B	220.7 A
Waipio	90.5 C (1.8)	54.2 A (0.7)	111.5 A (4.3)	0.9 B (0.02)	257.1 A	4.5 A (0.44)	5.6 A (0.3)	6.8 A	39.9 A (1.3)	51.8 A	205.3 A

[a]Sum of cations

[b]Sum of anions

[c]Means in the same column followed by same capital letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

[d]Ionic concentrations in the unit of % on a dry weight basis.

of soluble oxalate in plants grown at Kukaiau (Table 4.62). On the other hand, Waipio plants had lower tissue Ca and higher tissue K than Kukaiau plants (Table 4.61) which probably led to a higher proportion of soluble oxalate and a lower proportion of Ca oxalate than at Kukaiau (Table 4.62). Plant Mg and soluble oxalate contents at Iole were lower than in plants from Waipio while Ca and insoluble oxalate contents were higher.

Table 4.62

Comparative concentrations of different forms of oxalate as percentage of soluble + insoluble oxalate in taro leaves from three sites

Site	% of soluble + insoluble oxalate	
	Soluble* oxalate	Insoluble* oxalate
Kukaiau	17.2 C	82.8 A
Iole	33.5 B	66.5 A
Waipio	49.2 A	50.8 A

* Means in the same column followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

de la Pena and Plucknett (1969) found that addition of K to upland and lowland taro reduced the concentration of Ca as well as Mg. Simple correlation (Appendix F) of data from all sites shows that soil Ca was negatively correlated with tissue Ca, while tissue Ca was, in turn, negatively correlated with tissue K. Tissue K and soil K, however, were positively correlated indicating that K may be the most important soil variable influencing taro soluble oxalate content in Table 4.67.

The high concentration of Cl (1.0-1.3%) in taro leaves (Table 4.61) is of interest. It was more than 5 times higher than in leaves of amaranth and cassava (0.2-0.3% dry weight). According to Mengel and Kirkby (1978), Cl content of most plants generally range from 0.2-2.0% dry weight. For Cl sensitive crops, the reduction in yields was associated with tissue levels of 0.5-2.0% Cl. Spinach and beetroot are considered halophytes and contain Cl content ranging from 0.5-2.2% dry weight (Vityakon, 1979). These facts suggest that taro is of high Cl plant.

Oxalate and calcium concentration in taro leaves

Approximately 40 to 50 percent of Ca was in the forms of Ca oxalate (Table 4.63). Therefore, about half of the total tissue Ca in taro leaves should not be available to humans. The plant maintained a sizable soluble oxalate pool despite a large quantity of Ca unbound by oxalate. The mechanism by which taro maintains a high soluble oxalate pool in the presence of high plant Ca concentration cannot be explained at this time.

Relationship between oxalate and cation excess

Oxalate constituted from 30 to 40 percent of the cation excess in plants at the various sites (Table 4.64). Significant relationships between oxalates and cation excess were found in insoluble oxalate from combined data of three experimental sites and soluble and insoluble oxalate in Waipio site (Table 4.65). The sum of soluble and insoluble oxalate was not significantly correlated with cation excess. In

Table 4.63

Calcium in the form of calcium oxalate in taro leaves grown at three sites

Site	cmol kg^{-1} dry weight		
	Insoluble oxalate	Tissue Ca	Ca oxalate (% tissue Ca)
Kukaiau	52.5	131.7	39.9
Iole	56.7	110.3	51.4
Waipio	42.4	90.5	46.9

Table 4.64

Total oxalate as percentage of cation excess in taro leaves from three experimental sites

Site	% cation excess
Kukaiau	31.1
Iole	38.6
Waipio	40.7

contrast to other plants, it appears that oxalates in taro were more closely related with specific cations (Table 4.58) than with cation excess.

Total N, nitrate-N and crude protein contents

Significantly higher total N was found in taro leaves from the Iole site than in leaves from Kukaiau and Waipio (Table 4.66). This is likely because Iole soil has higher N content. The levels of nitrate-N in the leaves were below the dangerous level in all cases.

At Iole site crude protein content of taro leaves was similar to that of amaranth and cassava while at Kukaiau the levels were lower (Tables 4.66, 4.52, and 4.18).

Table 4.65

Correlation between oxalates and cation excess in taro leaves

oxalate	correlation coefficient (Probability > |r|)			
	combined[a] 3 sites	Kukaiau[b]	Iole[b]	Waipio[b]
Soluble	ns*	ns	ns	-0.7170 (0.0039)
Insoluble	0.3854 (0.0154)	ns ns	ns ns	0.7747 (0.0011)
Soluble+ Insoluble	ns	ns	ns	ns

* ns = non-significant

[a]Number of observations = 42

[b]Number of observations = 14

Table 4.66

Total N, nitrate-N and crude protein concentrations of taro leaves grown at three sites

Site	% dry weight		
	Total N*	Nitrate-N*	Crude protein*
Kukaiau	3.9 B	0.10 A	24.4 B
Iole	4.6 A	0.10 A	28.8 A
Waipio	3.8 B	0.09 A	23.8 B

* Means in the same column followed by the same letter are not significantly different at 0.05 probability level (Waller-Duncan's multiple range test).

4.4.3 Relationships between oxalates in taro leaves and soil and climatic variables

Soluble oxalate in taro leaves was positively correlated with soil Ca, Mg, K, and Na and negatively correlated with soil P (Table 4.67). This is consistent with the cation-anion balance concept in which increasing cation content leads to an increase in cation excess and consequently to an increase in the synthesis of organic acid. On the other hand, increasing anion concentration leads to a decrease in cation excess and a consequent decrease in organic acid content.

Soluble oxalate was correlated with climatic variables while no correlation was observed for insoluble oxalate or the sum of soluble and insoluble oxalate (Table 4.68). Soluble oxalate in taro leaves was positively correlated with air and soil temperature as was the case with amaranth and cassava. Both rainfall and relative humidity however, were negatively correlated with soluble oxalate. A correlation matrix (Appendix F) shows that radiation, air temperature, soil temperature, relative humidity, rainfall, and wind speed were all highly correlated. Thus, when radiation was high, temperature was high, rainfall was more likely and the air was more turbulent. It is likely that one variable serves as a surrogate for all others. In any case, the climate was sufficiently different among sites to have caused differences in the soluble oxalate content.

Table 4.67

Correlation between taro oxalates and soil variables from three experimental sites

Element	Corrleation coefficient* (Probability > |r|)		
	Soluble oxalate	Insoluble oxalate	Soluble+insoluble oxalate
Soil Ca	0.7020 (0.0001)	ns**	0.4756 (0.0022)
Mg	0.7400 (0.0001)	ns	ns
K	0.7161 (0.0001)	ns	ns
Na	0.6747 (0.0001)	ns	ns
P	-0.7618 (0.0001)	ns	-0.4714 (0.0025)

* Number of observations = 42
** ns = non-significant

Table 4.68

Correlation between taro oxalates and climatic variables from three experimental sites

Climatic variables	Correlation coefficient* (Probablity > |r|)		
	Soluble oxalate	Insoluble oxalate	Soluble+Insoluble oxalate
Average air temperature	0.5168 (0.0008)	ns**	ns
Average relative humidity	-0.5626 (0.0002)	ns	ns
Average topsoil temperature	ns	ns	ns
Average subsoil temperature	0.7113 (0.0001)	ns	ns
Rainfall	-0.7219 (0.0001)	ns	ns
Radiation	0.6227 (0.0001)	ns	ns
Wind speed	-0.5412 (0.0004)	ns	ns

* Number of observations = 42
** ns = non-significant

CHAPTER V

SUMMARY AND CONCLUSIONS

This study provides new evidence to support the hypothesis that plant composition is strongly influenced by the same environmental factors that regulate plant growth and development. While it is well known that soil fertility affects the mineral nutrition of plants, the effect of soil fertility on the antinutrient content of plants has heretofore not been well documented. This study also shows that the effect of soil fertility on plant composition in general, and anti-nutrient in particular, is strongly modified by atmospheric conditions. The situation is further complicated by the fact that plant utilization of soil phosphorus and bases is controlled first by soil nitrogen and only secondarily by the amount of phosphorus and bases present in the soil. Furthermore, plant composition is determined to a larger extent by plant genotype than by environmental factors.

Plant oxalate and cation excess is significantly related although in some cases better relationships are found between oxalate and individual cations. The results of this study support earlier studies which show that oxalate is produced in response to cation excess. In addition, the forms of oxalate produced depend on the dominant cations in the plant tissue.

Tables 5.1 and 5.2 summarized the effects of soil and climatic factors and cation excess on the oxalate and nitrate contents of three crops. Soil and climate affect cation excess (C-A) which in turn affect oxalate content.

Table 5.1 summarizes the important relationships that exist between soil-climate factors and oxalate and nitrate contents. The results show that these relationships differ for different crops. Through multiple regression analysis (Table 5.2) the key factors influencing individual plant constituents are identified. Formation of different forms of oxalate in the same plant is influenced by different environmental factors. The fact that solar radiation, air temperature and wind speed appear in the equations show that weather variables contribute measurably to plant composition.

These findings suggest that nutritional quality of crops can be controlled through crop selection and management of the environment. If as much attention is given to improving nutritional quality of food crops as is now given to increasing yields, the goal of meeting the nutritional needs of people will be more readily served.

Table 5.1

Soil, climatic factors and cation excess correlated with the concentration of oxalates and nitrate-N in amaranth, cassava and taro

Positive and negative signs are those of the correlation coefficients. Asterisks represent significance level, where there is no asterisk, the correlation is not significant.

Crop	Plant composition	Cation excess (C-A)	Soil					Climate					
			N	P	Ca	Mg	K	Av. temperature Air	Av. temperature Subsoil	Rainfall	Radiation	Wind speed	Relative humidity
AMARANTH	Soluble oxalate	-	+	-	-*	-	-	+	-	+	-	-	-
	Insol. oxalate	+**	+	-*	-	-	-	-	-	+**	-	-	+**
	Total oxalate	+**	+**	-	-**	-**	-*	-	-	+**	-**	-**	+
	Sol. + Insol. oxalate	+**	+*	-*	-**	-	-	-	-	+*	-**	-	+
	NO_3-N	-	+**	-	-**	-**	-**	-*	-	+**	-**	-**	+
CASSAVA	Insol. oxalate	+		+	-	+*	+	+	+*	-	+	+	-*
	Total oxalate	+		-	+	+*	+*	+	+*	-*	+	-	-
	NO_3-N	-		-*	+	+**	+**	+**	+**	-**	+**	+	-
TARO	Soluble oxalate	-		-**	+**	+**	+**	+**	+**	-**	+**	-**	-**
	Insol. oxalate	+*		+	-	-	-	-	-	+	-	+	+
	Sol. + insol. oxalate	+		-**	+**	+	-	+	+	-	+	-	-
	NO_3-N	-		+	-	-	-	-	-	+	-	+	+

Table 5.2

Variables identified through multiple regression analysis to contribute significantly to the oxalate and nitrate contents of amaranth

Plant composition (Y)[a]	X variables[b]	Contributions[c]	
Total oxalate (NI)	SRSQ	-	ns
	PLEVEL	-	*
	SOLMG	+	**
	SOLK	+	*
Total oxalate (I)	SRSQ	+	**
	NLEVEL	+	**
	SOLK	+	ns
	AIR4SQ	-	**
Soluble oxalate (NI)	SOLK	+	**
	PLEVEL	-	**
	SOLCA	-	**
	SOLP	+	ns
Soluble oxalate (I)	AIR2	+	**
	PLEVEL	-	**
Insoluble oxalate (NI)	SOLP	-	**
	PLEVEL	+	**
Insoluble oxalate (I)	AIR3	-	**
	NLEVEL	+	*
	PLEVEL	+	ns
Nitrate-N (NI)	WSPSQ	-	ns
	NLEVEL	+	**
	SOLMG	-	**
	SOLK	+	*
Nitrate-N (I)	AIR2SQ	+	**
	NLEVEL	+	**
	SOLTN	+	**

Table 5.2 (continued) Variables identified through multiple regression analysis to contribute significantly to the oxalate and nitrate contents of amaranth

Notes:

[a]NI = non-irrigated plants
I = irrigated plants

[b]SRSQ	=	Square of solar radiation
PLEVEL	=	Fertilizer P rate
SOLMG	=	Soil magnesium content
SOLK	=	Soil potassium content
NLEVEL	=	Fertilizer N rate
AIR4SQ	=	Square of the difference between maximum and minimum temperature
SOLCA	=	Soil Calcium content
SOLP	=	Soil phosphorus content
AIR2	=	Minimum air temperture
AIR3	=	Average air temperature
WSPSQ	=	Square of wind speed
AIR2SQ	=	Square of minimum air temperature
SOLTN	=	Soil total nitrogen content

[c]Positive and negative signs are those of the parameter estimates or regression coefficients in the regression equations. Asterisks indicate the significance level (Probability > /t/).

Appendix A. Analysis of variance of various dependent variables using combined data of amaranth experiments from three sites.

DEPENDENT VARIABLE: DW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	161983.94320755	5585.65321405	1.76	0.0829	0.689963	90.8982
ERROR	23	72788.15000000	3164.70217391		ROOT MSE		DW MEAN
CORRECTED TOTAL	52	234772.09320755			56.25568570		61.88867925

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	53900.48863238	8.52	0.0017	2	46752.66914530	7.39	0.0033
REP(LOC)	6	28205.65624183	1.49	0.2272	6	28750.16394444	1.51	0.2179
IRR	1	4.90928030	0.00	0.9689	1	30.69160000	0.01	0.9224
LOC*IRR	2	7244.04052128	1.14	0.3359	2	5937.61000000	0.94	0.4058
REP*IRR(LOC)	6	33153.24519841	1.75	0.1553	6	31278.73727778	1.65	0.1795
FER	2	6017.86287582	0.95	0.4011	2	5605.98299145	0.89	0.4260
LOC*FER	4	10507.14401307	0.83	0.5198	4	10201.19198413	0.81	0.5341
IRR*FER	2	11415.57969841	1.80	0.1872	2	11715.56418803	1.85	0.1797
LOC*IRR*FER	4	11535.01674603	0.91	0.4740	4	11535.01674603	0.91	0.4740

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	46752.66914530	4.68	0.0552

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	30.69160000	0.01	0.9413
LOC*IRR	2	5937.61000000	0.57	0.5937

DEPENDENT VARIABLE: OX

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	30674.42102030	1057.73865587	2.32	0.0230	0.753286	11.5023
ERROR	22	10046.39507778	456.65432172		ROOT MSE		OX MEAN
CORRECTED TOTAL	51	40720.81609808			21.36947172		185.78480769

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	13080.02383697	14.32	0.0001	2	13063.06080556	14.30	0.0001
REP(LOC)	6	2510.51038611	0.92	0.5019	6	2025.96052500	0.74	0.6236
IRR	1	143.89200441	0.32	0.5802	1	74.55628929	0.16	0.6901
LOC*IRR	2	720.58470503	0.79	0.4667	2	467.43162500	0.51	0.6064
REP*IRR(LOC)	6	1503.68849889	0.55	0.7656	6	1603.49258611	0.59	0.7384
FER	2	7415.00198824	8.12	0.0023	2	6985.42854444	7.65	0.0030
LOC*FER	4	618.96349621	0.34	0.8488	4	691.88775952	0.38	0.8213
IRR*FER	2	2253.11882587	2.47	0.1080	2	2357.31250000	2.58	0.0984
LOC*IRR*FER	4	2428.63727857	1.33	0.2903	4	2428.63727857	1.33	0.2903

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	13063.06080556	19.34	0.0024

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	74.55628929	0.28	0.6163
LOC*IRR	2	467.43162500	0.87	0.4642

DEPENDENT VARIABLE: OX2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	29545.43161765	1018.80798682	5.59	0.0001	0.885238	15.4143
ERROR	21	3830.27583333	182.39408730		ROOT MSE		OX2 MEAN
CORRECTED TOTAL	50	33375.70745098			13.50533551		87.61568627

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	7790.28033987	21.36	0.0001	2	7873.92118056	21.58	0.0001
REP(LOC)	6	3478.80744444	3.18	0.0222	6	3360.22598291	3.07	0.0256
IRR	1	103.28832129	0.57	0.4601	1	59.16035714	0.32	0.5750
LOC*IRR	2	987.52992026	2.71	0.0899	2	768.43340278	2.11	0.1466
REP*IRR(LOC)	6	847.28975845	0.77	0.5989	6	901.10940171	0.82	0.5645
FER	2	9739.90931373	26.70	0.0001	2	7194.08425214	19.72	0.0001
LOC*FER	4	4741.53954739	6.50	0.0014	4	4796.87286905	6.57	0.0014
IRR*FER	2	75.70569048	0.21	0.8142	2	69.83775641	0.19	0.8272
LOC*IRR*FER	4	1781.08128175	2.44	0.0786	4	1781.08128175	2.44	0.0786

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	7873.92118056	7.03	0.0268

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	59.16035714	0.39	0.5534
LOC*IRR	2	768.43340278	2.56	0.1572

DEPENDENT VARIABLE: OX3

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	15119.35227124	521.35697487	4.03	0.0008	0.847740	9.9340
ERROR	21	2715.53361111	129.31112434		ROOT MSE		OX3 MEAN
CORRECTED TOTAL	50	17834.88588235			11.37150493		114.47058824

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	4017.31466013	15.53	0.0001	2	3782.33027778	14.62	0.0001
REP(LOC)	6	1682.74172222	2.17	0.0876	6	859.90401709	1.11	0.3906
IRR	1	396.89855622	3.07	0.0944	1	569.70321429	4.41	0.0481
LOC*IRR	2	4519.61253798	17.48	0.0001	2	3534.00250000	13.66	0.0002
REP*IRR(LOC)	6	865.88007246	1.12	0.3865	6	885.74948718	1.14	0.3733
FER	2	1244.78235294	4.81	0.0190	2	1131.71006410	4.38	0.0258
LOC*FER	4	1084.94628595	2.10	0.1172	4	1033.68604365	2.00	0.1317
IRR*FER	2	875.70054762	3.39	0.0531	2	810.54006410	3.13	0.0644
LOC*IRR*FER	4	431.47553571	0.83	0.5186	4	431.47553571	0.83	0.5186

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	3782.33027778	13.20	0.0064

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	569.70321429	3.86	0.0971
LOC*IRR	2	3534.00250000	11.97	0.0080

DEPENDENT VARIABLE: OX2_3

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	26769.12150327	923.07315529	3.79	0.0012	0.839495	7.7251
ERROR	21	5118.03888889	243.71613757		ROOT MSE		OX2_3 MEAN
CORRECTED TOTAL	50	31887.16039216			15.61141049		202.08627451

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	4491.12916993	9.21	0.0013	2	4466.84090278	9.16	0.0014
REP(LOC)	6	7541.51672222	5.16	0.0021	6	5738.09350427	3.92	0.0087
IRR	1	905.13124699	3.71	0.0676	1	996.03571429	4.09	0.0561
LOC*IRR	2	1282.58545108	2.63	0.0956	2	1007.34923611	2.07	0.1516
REP*IRR(LOC)	6	1143.39780193	0.78	0.5935	6	1149.07401709	0.79	0.5908
FER	2	4452.20049020	9.13	0.0014	2	3080.68675214	6.32	0.0071
LOC*FER	4	4863.59406536	4.99	0.0055	4	4719.81592063	4.84	0.0063
IRR*FER	2	1212.84104762	2.49	0.1072	2	1041.69641026	2.14	0.1430
LOC*IRR*FER	4	876.72550794	0.90	0.4820	4	876.72550794	0.90	0.4820

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	4466.84090278	2.34	0.1778

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	996.03571429	5.20	0.0628
LOC*IRR	2	1007.34923611	2.63	0.1513

DEPENDENT VARIABLE: TN

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	26.49339419	0.91356532	10.14	0.0001	0.930392	7.4624
ERROR	22	1.98212889	0.09009677		ROOT MSE		TN MEAN
CORRECTED TOTAL	51	28.47552308			0.30016124		4.02230769

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	15.68727933	87.06	0.0001	2	15.22261719	84.48	0.0001
REP(LOC)	6	1.42340708	2.63	0.0448	6	1.24943475	2.31	0.0699
IRR	1	0.37758519	4.19	0.0528	1	0.54522250	6.05	0.0222
LOC*IRR	2	2.98283335	16.55	0.0001	2	2.98079235	16.54	0.0001
REP*IRR(LOC)	6	0.98276812	1.82	0.1418	6	0.89547717	1.66	0.1791
FER	2	3.77162004	20.93	0.0001	2	3.36979891	18.70	0.0001
LOC*FER	4	0.57809056	1.60	0.2087	4	0.61015731	1.69	0.1875
IRR*FER	2	0.19644556	1.09	0.3536	2	0.20136184	1.12	0.3450
LOC*IRR*FER	4	0.49336495	1.37	0.2769	4	0.49336495	1.37	0.2769

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	15.22261719	36.55	0.0004

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.54522250	3.65	0.1045
LOC*IRR	2	2.98079235	9.99	0.0123

DEPENDENT VARIABLE: CC_A

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	23827.73762294	821.64612493	2.69	0.0098	0.779950	5.4646
ERROR	22	6722.62040574	305.57365481		ROOT MSE		CC_A MEAN
CORRECTED TOTAL	51	30550.35802868			17.48066517		319.89121154

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	9578.85374351	15.67	0.0001	2	10073.49258838	16.48	0.0001
REP(LOC)	6	838.15596393	0.46	0.8322	6	774.86893659	0.42	0.8559
IRR	1	1733.29843932	5.67	0.0263	1	1858.55735195	6.08	0.0219
LOC*IRR	2	222.01862814	0.36	0.6995	2	248.45498341	0.41	0.6709
REP*IRR(LOC)	6	3642.07162111	1.99	0.1112	6	3802.57991659	2.07	0.0981
FER	2	1409.22027253	2.31	0.1233	2	957.80107189	1.57	0.2310
LOC*FER	4	3527.39921805	2.89	0.0462	4	3572.29800966	2.92	0.0443
IRR*FER	2	994.68591746	1.63	0.2192	2	1185.21693417	1.94	0.1676
LOC*IRR*FER	4	1882.03381889	1.54	0.2255	4	1882.03381889	1.54	0.2255

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	10073.49258838	39.00	0.0004

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	1858.55735195	2.93	0.1376
LOC*IRR	2	248.45498341	0.20	0.8271

DEPENDENT VARIABLE: CA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	19533.06666667	673.55402299	4.50	0.0003	0.855681	10.1976
ERROR	22	3294.43333333	149.74696970		ROOT MSE		CA MEAN
CORRECTED TOTAL	51	22827.50000000			12.23711444		120.00000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	9709.27777778	32.42	0.0001	2	10222.69738562	34.13	0.0001
REP(LOC)	6	1416.43055556	1.58	0.2010	6	1707.17777778	1.90	0.1260
IRR	1	0.76918605	0.01	0.9435	1	8.63350694	0.06	0.8125
LOC*IRR	2	2565.47803610	8.57	0.0018	2	2586.30849673	8.64	0.0017
REP*IRR(LOC)	6	1304.25277778	1.45	0.2405	6	1537.91515152	1.71	0.1654
FER	2	1581.89859307	5.28	0.0134	2	1623.45657962	5.42	0.0122
LOC*FER	4	1536.09004329	2.56	0.0668	4	1630.81059028	2.72	0.0557
IRR*FER	2	382.59469697	1.28	0.2986	2	556.66395289	1.86	0.1798
LOC*IRR*FER	4	1036.27500000	1.73	0.1793	4	1036.27500000	1.73	0.1793

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	10222.69738562	17.96	0.0029

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	8.63350694	0.03	0.8604
LOC*IRR	2	2586.30849673	5.05	0.0519

DEPENDENT VARIABLE: MG

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	9405.24194444	324.31868774	5.93	0.0001	0.886633	6.7381
ERROR	22	1202.57555556	54.66252525		ROOT MSE		MG MEAN
CORRECTED TOTAL	51	10607.81750000			7.39341093		109.72500000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	3279.80361111	30.00	0.0001	2	3249.08611111	29.72	0.0001
REP(LOC)	6	1293.66322222	3.94	0.0079	6	1236.19353535	3.77	0.0099
IRR	1	514.39779845	9.41	0.0056	1	446.66944444	8.17	0.0091
LOC*IRR	2	2028.21184258	18.55	0.0001	2	2022.59277770	18.50	0.0001
REP*IRR(LOC)	6	677.21102564	2.06	0.0994	6	607.68626263	1.65	0.1349
FER	2	428.88276190	3.92	0.0349	2	386.14247824	3.53	0.0467
LOC*FER	4	308.52400577	1.41	0.2632	4	281.69059028	1.29	0.3050
IRR*FER	2	29.44458649	0.27	0.7664	2	39.94057348	0.37	0.6981
LOC*IRR*FER	4	845.10309028	3.87	0.0159	4	845.10309028	3.87	0.0159

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	3249.08611111	7.88	0.0209

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	446.66944444	4.41	0.0805
LOC*IRR	2	2022.59277778	9.99	0.0123

DEPENDENT VARIABLE: K

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	19100.60673077	658.64161141	11.98	0.0001	0.940457	5.9394
ERROR	22	1209.32000000	54.96909091		ROOT MSE		K MEAN
CORRECTED TOTAL	51	20309.92673077			7.41411430		124.82884615

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	15072.96867521	137.10	0.0001	2	15249.02454248	138.71	0.0001
REP(LOC)	6	219.90172222	0.67	0.6772	6	250.06292929	0.76	0.6101
IRR	1	74.92931008	1.36	0.2555	1	114.18767361	2.08	0.1636
LOC*IRR	2	1540.36003180	14.01	0.0001	2	1447.08924837	13.16	0.0002
REP*IRR(LOC)	6	492.30865812	1.49	0.2267	6	444.01101818	1.35	0.2794
FER	2	360.28477489	3.28	0.0568	2	337.20438300	3.07	0.0668
LOC*FER	4	1044.27355844	4.75	0.0065	4	1068.91277778	4.86	0.0058
IRR*FER	2	27.49899306	0.25	0.7009	2	11.68776242	0.11	0.8996
LOC*IRR*FER	4	268.08100694	1.22	0.3311	4	268.00100694	1.22	0.3311

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	15249.02454248	182.94	0.0001

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	114.18767361	1.54	0.2605
LOC*IRR	2	1447.08924837	9.78	0.0129

DEPENDENT VARIABLE: NA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	429.85070085	14.82243796	46.15	0.0001	0.983827	9.1296
ERROR	22	7.06622222	0.32119192		ROOT MSE		NA MEAN
CORRECTED TOTAL	51	436.91692308			0.56673796		6.20769231

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	149.74477030	233.11	0.0001	2	151.06877778	235.17	0.0001
REP(LOC)	6	2.58715278	1.34	0.2609	6	2.20549495	1.14	0.3704
IRR	1	83.34760465	259.49	0.0001	1	71.69006250	223.20	0.0001
LOC*IRR	2	189.81336116	295.48	0.0001	2	189.70564052	295.32	0.0001
REP*IRR(LOC)	6	0.88570085	0.46	0.8304	6	0.92004040	0.48	0.8178
FER	2	1.35206494	2.10	0.1457	2	1.45575422	2.27	0.1274
LOC*FER	4	1.44879365	1.13	0.3691	4	1.48311806	1.15	0.3576
IRR*FER	2	0.31136364	0.48	0.6223	2	0.31639939	0.49	0.6177
LOC*IRR*FER	4	0.35988889	0.28	0.8877	4	0.35988889	0.28	0.8877

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	151.06877778	205.49	0.0001

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	71.69006250	467.52	0.0001
LOC*IRR	2	189.70564052	618.58	0.0001

DEPENDENT VARIABLE: P

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	68.79967521	2.37240259	7.39	0.0001	0.906939	18.2959
ERROR	22	7.05955556	0.32088889		ROOT MSE		P MEAN
CORRECTED TOTAL	51	75.85923077			0.56647055		3.09615385

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	5.24374466	8.17	0.0022	2	5.62799346	8.77	0.0016
REP(LOC)	6	5.07315278	2.63	0.0444	6	5.02145455	2.61	0.0460
IRR	1	14.74140310	45.94	0.0001	1	12.41367361	38.69	0.0001
LOC*IRR	2	16.10981912	25.10	0.0001	2	16.66067320	25.96	0.0001
REP*IRR(LOC)	6	1.59277778	0.83	0.5613	6	1.38064646	0.72	0.6400
FER	2	16.47985714	25.68	0.0001	2	16.40856528	25.57	0.0001
LOC*FER	4	0.69564791	0.54	0.7066	4	0.54947222	0.43	0.7867
IRR*FER	2	2.87102273	4.47	0.0234	2	2.75697286	4.30	0.0266
LOC*IRR*FER	4	5.99225000	4.67	0.0070	4	5.99225000	4.67	0.0070

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	5.62799346	3.36	0.1048

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	12.41367361	53.95	0.0003
LOC*IRR	2	16.66067320	36.20	0.0004

DEPENDENT VARIABLE: S

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	83.19647863	2.86884409	4.09	0.0006	0.843633	9.0926
ERROR	22	15.42044444	0.70092929		ROOT MSE		S MEAN
CORRECTED TOTAL	51	98.61692308			0.83721520		9.20769231

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	27.65143697	19.72	0.0001	2	28.44043791	20.29	0.0001
REP(LOC)	6	8.81348611	2.10	0.0951	6	9.13591919	2.17	0.0852
IRR	1	0.10793798	0.15	0.6985	1	0.18000694	0.26	0.6174
LOC*IRR	2	6.27609620	4.48	0.0234	2	6.36279085	4.54	0.0224
REP*IRR(LOC)	6	3.13796581	0.75	0.6188	6	2.67248485	0.64	0.7007
FER	2	11.49900433	8.20	0.0022	2	10.57339068	7.54	0.0032
LOC*FER	4	14.97968254	5.34	0.0037	4	15.19139583	5.42	0.0034
IRR*FER	2	8.38030619	5.98	0.0084	2	8.20251510	5.85	8.0092
LOC*IRR*FER	4	2.35056250	0.84	0.5156	4	2.35056250	0.84	0.5156

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	28.44043791	9.34	0.0144

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.18000694	0.40	0.5484
LOC*IRR	2	6.36279085	7.14	0.0259

DEPENDENT VARIABLE: CN03

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	10085.69494687	347.78258437	7.93	0.0001	0.912687	31.1067
ERROR	22	964.85602796	43.85709218		ROOT MSE		CN03 MEAN
CORRECTED TOTAL	51	11050.55097483			6.62246874		21.28955769

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	4253.13023828	48.49	0.0001	2	4195.01888053	47.83	0.0001
REP(LOC)	6	434.94311532	1.65	0.1000	6	384.12788103	1.46	0.2377
IRR	1	594.60845560	13.56	0.0013	1	677.11915126	15.44	0.0007
LOC*IRR	2	529.18158622	6.03	0.0081	2	542.17082720	6.18	0.0074
REP*IRR(LOC)	6	293.08194675	1.11	0.3862	6	305.98509740	1.16	0.3611
FER	2	2387.03758561	27.21	0.0001	2	1955.11465509	22.29	0.0001
LOC*FER	4	871.94863629	4.97	0.0052	4	923.23447702	5.26	0.0040
IRR*FER	2	185.71796149	2.12	0.1442	2	219.87918835	2.51	0.1045
LOC*IRR*FER	4	536.04542132	3.06	0.0382	4	536.04542132	3.06	0.0382

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	4195.01888053	32.76	0.0006

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	677.11915126	13.20	0.0108
LOC*IRR	2	542.17082720	5.32	0.0470

DEPENDENT VARIABLE: CL

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	40.72136752	1.40418509	9.37	0.0001	0.925130	5.3813
ERROR	22	3.29555556	0.14979798		ROOT MSE		CL MEAN
CORRECTED TOTAL	51	44.01692308			0.38703744		7.19230769

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	5.21692308	17.41	0.0001	2	5.19588235	17.34	0.0001
REP(LOC)	6	2.58700000	2.88	0.0317	6	2.41797980	2.69	0.0411
IRR	1	2.16931006	14.48	0.0010	1	1.95069444	13.02	0.0016
LOC*IRR	2	5.81883522	19.42	0.0001	2	5.84477124	19.51	0.0001
REP*IRR(LOC)	6	1.17318803	1.31	0.2960	6	0.78969697	0.88	0.5265
FER	2	15.48659307	51.69	0.0001	2	14.82580645	49.49	0.0001
LOC*FER	4	5.70739683	9.53	0.0001	4	5.77674479	9.64	0.0001
IRR*FER	2	1.17183475	3.91	0.0352	2	1.08763953	3.63	0.0434
LOC*IRR*FER	4	1.39028646	2.32	0.0888	4	1.39028646	2.32	0.0888

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	5.19588235	6.45	0.0320

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	1.95069444	14.82	0.0085
LOC*IRR	2	5.84477124	22.20	0.0017

DEPENDENT VARIABLE: OXPRO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	1370.32547083	47.25260244	1.68	0.1060	0.689230	98.3141
ERROR	22	617.87267008	28.08512137		ROOT MSE		OXPRO MEAN
CORRECTED TOTAL	51	1988.19814091			5.29953973		5.39041644

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	495.04570986	8.81	0.0015	2	463.44082323	8.25	0.0021
REP(LOC)	6	192.24677916	1.14	0.3722	6	136.04367554	0.81	0.5752
IRR	1	2.69880554	0.10	0.7595	1	11.35267560	0.40	0.5315
LOC*IRR	2	90.25966452	1.61	0.2232	2	103.57776817	1.84	0.1818
REP*IRR(LOC)	6	241.54006843	1.43	0.2468	6	186.25425348	1.11	0.3907
FER	2	20.87636827	0.37	0.6938	2	8.72135303	0.16	0.8571
LOC*FER	4	95.52468136	0.85	0.5087	4	125.80635907	1.12	0.3725
IRR*FER	2	89.57848280	1.59	0.2255	2	112.41489910	2.00	0.1590
LOC*IRR*FER	4	142.55491089	1.27	0.3121	4	142.55491089	1.27	0.3121

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	463.44082323	10.22	0.0117

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	11.35267560	0.37	0.5675
LOC*IRR	2	103.57776817	1.67	0.2654

DEPENDENT VARIABLE: OX2PRO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	180.92517959	6.23879930	4.64	0.0003	0.865086	52.6922
ERROR	21	28.21612910	1.34362520		ROOT MSE		OX2PRO MEAN
CORRECTED TOTAL	50	209.14130869			1.15914848		2.19984946

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	57.35090060	21.34	0.0001	2	47.29569053	17.60	0.0001
REP(LOC)	6	29.15937187	3.62	0.0127	6	41.01352634	5.09	0.0023
IRR	1	0.42917358	0.32	0.5779	1	0.33370103	0.25	0.6234
LOC*IRR	2	14.25890201	5.31	0.0136	2	9.24462086	3.44	0.0510
REP*IRR(LOC)	6	50.66247590	6.28	0.0007	6	50.02870139	6.21	0.0007
FER	2	7.44869945	2.77	0.0854	2	9.69550232	3.61	0.0450
LOC*FER	4	16.08731322	2.99	0.0422	4	17.46074491	3.25	0.0319
IRR*FER	2	0.09540934	0.04	0.9652	2	0.07720909	0.03	0.9717
LOC*IRR*FER	4	5.43293363	1.01	0.4242	4	5.43293363	1.01	0.4242

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	47.29569053	3.46	0.1002

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.33370103	0.04	0.8480
LOC*IRR	2	9.24462086	0.55	0.6013

DEPENDENT VARIABLE: OX3PRO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	909.69247103	31.36870590	10.52	0.0001	0.935590	48.5498
ERROR	21	62.62660261	2.98221917		ROOT MSE		OX3PRO MEAN
CORRECTED TOTAL	50	972.31907364			1.72691030		3.55698701

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	270.96996075	45.43	0.0001	2	231.82493311	38.87	0.0001
REP(LOC)	6	155.22881006	8.68	0.0001	6	226.31773602	12.65	0.0001
IRR	1	12.77723075	4.28	0.0510	1	11.65479605	3.91	0.0613
LOC*IRR	2	124.76557587	20.92	0.0001	2	79.43877109	13.32	0.0002
REP*IRR(LOC)	6	204.14172731	11.41	0.0001	6	211.79528326	11.84	0.0001
FER	2	71.68032885	12.02	0.0003	2	78.32234465	13.13	0.0002
LOC*FER	4	55.79711093	4.68	0.0074	4	56.79080664	4.76	0.0068
IRR*FER	2	3.52202707	0.59	0.5630	2	1.67691309	0.28	0.7577
LOC*IRR*FER	4	10.80969945	0.91	0.4783	4	10.80969945	0.91	0.4783

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	231.82493311	3.07	0.1205

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	11.65479605	0.33	0.5864
LOC*IRR	2	79.43877109	1.13	0.3846

DEPENDENT VARIABLE: OX2_3PRO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	1871.19986692	64.52413334	8.16	0.0001	0.918476	48.8574
ERROR	21	166.08891053	7.90899574		ROOT MSE		OX2_3PRO MEAN
CORRECTED TOTAL	50	2037.28877745			2.81229368		5.75613059

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	574.72583796	36.33	0.0001	2	485.73760991	30.71	0.0001
REP(LOC)	6	317.52566634	6.69	0.0005	6	457.79418759	9.65	0.0001
IRR	1	17.84671518	2.26	0.1479	1	15.93270179	2.01	0.1705
LOC*IRR	2	222.13973772	14.04	0.0001	2	141.85786538	8.97	0.0015
REP*IRR(LOC)	6	456.71654666	9.62	0.0001	6	465.10602651	9.80	0.0001
FER	2	123.79445234	7.83	0.0029	2	140.16759132	8.86	0.0016
LOC*FER	4	126.90285599	4.01	0.0143	4	131.78225917	4.17	0.0122
IRR*FER	2	4.82291971	0.30	0.7404	2	2.33236113	0.15	0.8638
LOC*IRR*FER	4	26.72513500	0.84	0.5125	4	26.72513500	0.84	0.5125

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	485.73760991	3.18	0.1142

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	15.93270179	0.21	0.6662
LOC*IRR	2	141.85786538	0.92	0.4500

DEPENDENT VARIABLE: TNUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	315.40643097	10.87603383	2.13	0.0356	0.737487	87.4313
ERROR	22	112.27106226	5.10323010		ROOT MSE		TNUPT MEAN
CORRECTED TOTAL	51	427.67749323			2.25903300		2.58378115

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	124.03925785	12.15	0.0003	2	118.22979106	11.58	0.0004
REP(LOC)	6	35.02411546	1.14	0.3707	6	41.43848854	1.35	0.2764
IRR	1	0.01779325	0.00	0.9534	1	0.01349362	0.00	0.9595
LOC*IRR	2	11.87712397	1.16	0.3308	2	12.06351985	1.18	0.3254
REP*IRR(LOC)	6	60.04253057	1.96	0.1154	6	59.66977697	1.95	0.1174
FER	2	6.05266650	0.59	0.5612	2	5.59608824	0.55	0.5856
LOC*FER	4	19.83482453	0.97	0.4429	4	26.60615528	1.30	0.2995
IRR*FER	2	21.46275307	2.10	0.1460	2	25.26720711	2.48	0.1072
LOC*IRR*FER	4	37.05516577	1.82	0.1619	4	37.05516577	1.82	0.1619

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	118.22979106	8.56	0.0175

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.01349362	0.00	0.9718
LOC*IRR	2	12.06351985	0.61	0.5756

DEPENDENT VARIABLE: CAUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	185.98212530	6.41317673	1.73	0.0950	0.694834	109.7495
ERROR	22	81.68204721	3.71282033		ROOT MSE		CAUPT MEAN
CORRECTED TOTAL	51	267.66417251			1.92686801		1.75569635

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	70.26926874	9.46	0.0011	2	69.90583438	9.41	0.0011
REP(LOC)	6	22.98775276	1.03	0.4314	6	34.92968774	1.57	0.2035
IRR	1	2.31814802	0.62	0.4379	1	3.02940802	0.82	0.3762
LOC*IRR	2	22.16023306	2.98	0.0713	2	20.64675113	2.78	0.0838
REP*IRR(LOC)	6	25.81194755	1.16	0.3632	6	35.15717545	1.58	0.2005
FER	2	10.72578076	1.44	0.2574	2	12.13515887	1.63	0.2179
LOC*FER	4	13.38812130	0.90	0.4800	4	17.35666077	1.17	0.3516
IRR*FER	2	7.49651270	1.01	0.3807	2	9.22302977	1.24	0.3083
LOC*IRR*FER	4	10.82436041	0.73	0.5818	4	10.82436041	0.73	0.5818

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	69.90583438	6.00	0.0370

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	3.02940802	0.52	0.4992
LOC*IRR	2	20.64675113	1.76	0.2501

DEPENDENT VARIABLE: MGUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	31.04856861	1.07064030	2.04	0.0441	0.729125	88.8196
ERROR	22	11.53473093	0.52430595		ROOT MSE		MGUPT MEAN
CORRECTED TOTAL	51	42.58329954			0.72408974		0.81523640

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	11.86727258	11.32	0.0004	2	11.34243347	10.82	0.0005
REP(LOC)	6	4.21511614	1.34	0.2819	6	5.03884243	1.60	0.1938
IRR	1	0.03298416	0.06	0.8043	1	0.07002644	0.13	0.7183
LOC*IRR	2	1.68874690	1.61	0.2225	2	1.68110974	1.60	0.2239
REP*IRR(LOC)	6	5.45586984	1.73	0.1601	6	5.60090764	1.78	0.1498
FER	2	0.58438550	0.56	0.5806	2	0.68490117	0.65	0.5302
LOC*FER	4	2.16117296	1.03	0.4137	4	2.88757614	1.38	0.2743
IRR*FER	2	2.18158415	2.08	0.1488	2	2.51249361	2.40	0.1144
LOC*IRR*FER	4	2.86143639	1.36	0.2784	4	2.86143639	1.36	0.2784

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	11.34243347	6.75	0.0291

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.07002644	0.08	0.7934
LOC*IRR	2	1.68110974	0.90	0.4550

DEPENDENT VARIABLE: KUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	353.05775377	12.17440530	2.18	0.0316	0.741974	79.1118
ERROR	22	122.77807647	5.58082166		ROOT MSE		KUPT MEAN
CORRECTED TOTAL	51	475.83583024			2.36237627		2.98612344

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	115.94632105	10.39	0.0007	2	109.26545098	9.79	0.0009
REP(LOC)	6	49.75309009	1.49	0.2290	6	60.15893377	1.80	0.1463
IRR	1	0.55438091	0.10	0.7556	1	0.23646382	0.04	0.8388
LOC*IRR	2	12.32299225	1.10	0.3492	2	12.62330391	1.13	0.3408
REP*IRR(LOC)	6	52.00248565	1.55	0.2079	6	55.45660507	1.66	0.1792
FER	2	17.14281351	1.54	0.2375	2	17.11774459	1.53	0.2379
LOC*FER	4	37.03789846	1.66	0.1953	4	46.11437821	2.07	0.1200
IRR*FER	2	27.71340066	2.48	0.1066	2	32.09720129	2.88	0.0777
LOC*IRR*FER	4	40.58437120	1.82	0.1613	4	40.58437120	1.82	0.1613

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	109.26545098	5.45	0.0448

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.23646382	0.03	0.8782
LOC*IRR	2	12.62330391	0.68	0.5405

DEPENDENT VARIABLE: NAUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	0.19097197	0.00658524	2.15	0.0342	0.738975	70.9967
ERROR	22	0.06745628	0.00306619		ROOT MSE		NAUPT MEAN
CORRECTED TOTAL	51	0.25842825			0.05537323		0.07799413

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	0.04130449	6.74	0.0052	2	0.03725716	6.08	0.0079
REP(LOC)	6	0.02462949	1.34	0.2824	6	0.02902256	1.58	0.2007
IRR	1	0.00196054	0.64	0.4325	1	0.00203752	0.66	0.4237
LOC*IRR	2	0.01599707	2.61	0.0962	2	0.01599818	2.61	0.0962
REP*IRR(LOC)	6	0.03206937	1.74	0.1580	6	0.03504773	1.91	0.1251
FER	2	0.01001266	1.63	0.2182	2	0.00911378	1.49	0.2481
LOC*FER	4	0.02414091	1.97	0.1347	4	0.02820372	2.30	0.0910
IRR*FER	2	0.01675389	2.73	0.0871	2	0.01839146	3.00	0.0705
LOC*IRR*FER	4	0.02410355	1.97	0.1352	4	0.02410355	1.97	0.1352

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	0.03725716	3.85	0.0840

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00203752	0.35	0.5763
LOC*IRR	2	0.01599818	1.37	0.3237

DEPENDENT VARIABLE: PUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	1.29375298	0.04461217	3.43	0.0020	0.818795	65.8827
ERROR	22	0.28631707	0.01301441		ROOT MSE		PUPT MEAN
CORRECTED TOTAL	51	1.58007004			0.11408073		0.17315732

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	0.28721778	11.03	0.0005	2	0.25816426	9.92	0.0009
REP(LOC)	6	0.07107396	0.91	0.5058	6	0.12479149	1.60	0.1948
IRR	1	0.00000329	0.00	0.9875	1	0.00002691	0.00	0.9641
LOC*IRR	2	0.04021994	1.55	0.2355	2	0.04008701	1.54	0.2372
REP*IRR(LOC)	6	0.13795387	1.77	0.1528	6	0.18405811	2.36	0.0655
FER	2	0.25352938	9.74	0.0009	2	0.24634361	9.46	0.0011
LOC*FER	4	0.15025313	2.89	0.0462	4	0.17999021	3.46	0.0245
IRR*FER	2	0.10722778	4.12	0.0302	2	0.13188931	5.07	0.0155
LOC*IRR*FER	4	0.24627385	4.73	0.0066	4	0.24627385	4.73	0.0066

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	0.25816426	6.21	0.0346

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00002691	0.00	0.9773
LOC*IRR	2	0.04000701	0.65	0.5543

DEPENDENT VARIABLE: SUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	4.28822994	0.14787000	2.46	0.0165	0.764230	85.1767
ERROR	22	1.32294690	0.06013395		ROOT MSE		SUPT MEAN
CORRECTED TOTAL	51	5.61117684			0.24522225		0.28789818

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	1.41148009	11.74	0.0003	2	1.34027178	11.14	0.0005
REP(LOC)	6	0.60779052	1.68	0.1720	6	0.63492411	1.76	0.1543
IRR	1	0.00000001	0.00	0.9997	1	0.00112168	0.02	0.8926
LOC*IRR	2	0.19830616	1.65	0.2152	2	0.20263484	1.68	0.2085
REP*IRR(LOC)	6	0.66449631	1.84	0.1371	6	0.65254234	1.81	0.1438
FER	2	0.20071887	1.67	0.2114	2	0.18286510	1.52	0.2407
LOC*FER	4	0.35340750	1.47	0.2454	4	0.42819208	1.78	0.1688
IRR*FER	2	0.42820744	3.56	0.0458	2	0.47404897	3.94	0.0344
LOC*IRR*FER	4	0.42382304	1.76	0.1726	4	0.42382304	1.76	0.1726

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	1.34027178	6.33	0.0332

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00112168	0.01	0.9224
LOC*IRR	2	0.20263484	0.93	0.4443

DEPENDENT VARIABLE: CNO3UPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	28.95884869	0.99858099	1.58	0.1362	0.675565	94.8423
ERROR	22	13.90729935	0.63214997		ROOT MSE		CNO3UPT MEAN
CORRECTED TOTAL	51	42.86614804			0.79507859		0.83831624

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	13.79743870	10.91	0.0005	2	12.75627104	10.09	0.0008
REP(LOC)	6	1.62888353	0.43	0.8513	6	3.04566020	0.80	0.5782
IRR	1	0.90032618	1.42	0.2454	1	0.93470430	1.48	0.2369
LOC*IRR	2	0.87192728	0.69	0.5123	2	0.84962251	0.67	0.5209
REP*IRR(LOC)	6	6.30563118	1.66	0.1776	6	6.56682963	1.73	0.1608
FER	2	0.64234599	0.51	0.6085	2	0.17400975	0.14	0.8722
LOC*FER	4	1.48590837	0.59	0.6750	4	2.12793247	0.84	0.5137
IRR*FER	2	0.90916610	0.72	0.4983	2	1.34615841	1.06	0.3619
LOC*IRR*FER	4	2.41722137	0.96	0.4510	4	2.41722137	0.96	0.4510

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	12.75627104	12.57	0.0072

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.93470430	0.85	0.3911
LOC*IRR	2	0.84962251	0.39	0.6942

DEPENDENT VARIABLE: CLUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	29	1.18941065	0.04101416	2.30	0.0237	0.752275	83.1651
ERROR	22	0.39167453	0.01780339		ROOT MSE		CLUPT MEAN
CORRECTED TOTAL	51	1.58108518			0.13342934		0.16043911

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
LOC	2	0.32355786	9.09	0.0013	2	0.30637478	8.60	0.0017
REP(LOC)	6	0.18247664	1.71	0.1662	6	0.19803797	1.85	0.1347
IRR	1	0.00009060	0.01	0.9438	1	0.00070072	0.04	0.8446
LOC*IRR	2	0.05861622	1.65	0.2157	2	0.05941075	1.67	0.2115
REP*IRR(LOC)	6	0.18049761	1.69	0.1707	6	0.18790189	1.76	0.1545
FER	2	0.07958004	2.23	0.1307	2	0.07661700	2.15	0.1401
LOC*FER	4	0.12664877	1.78	0.1692	4	0.15367938	2.16	0.1075
IRR*FER	2	0.11169402	3.14	0.0633	2	0.12589510	3.54	0.0466
LOC*IRR*FER	4	0.12624889	1.77	0.1703	4	0.12624889	1.77	0.1703

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
LOC	2	0.30637478	4.64	0.0605

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP*IRR(LOC) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00070072	0.02	0.8860
LOC*IRR	2	0.05941075	0.95	0.4386

Appendix B. Analysis of variance of some dependent variables using data of amaranth experiment from Waipio site.

DEPENDENT VARIABLE: OX

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	7704.87791111	856.09754568	5.24	0.0145	0.854960	7.6881
ERROR	8	1307.10088889	163.38761111		ROOT MSE		OX MEAN
CORRECTED TOTAL	17	9011.97880000			12.78231634		166.26000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	130.68055556	0.80	0.3973	1	130.68055556	0.80	0.3973
REP(IRR)	4	831.39991111	1.27	0.3566	4	831.39991111	1.27	0.3566
FER	2	3834.65343333	11.73	0.0042	2	3834.65343333	11.73	0.0042
IRR*FER	2	2908.14401111	8.90	0.0092	2	2908.14401111	8.90	0.0092

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
	.	130.68055556	0.63	0.4722

DEPENDENT VARIABLE: TN

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	1.97024444	0.21891605	7.68	0.0043	0.896299	5.1464
ERROR	8	0.22795556	0.02849444		ROOT MSE		TN MEAN
CORRECTED TOTAL	17	2.19820000			0.16880298		3.28000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.28375556	9.96	0.0135	1	0.28375556	9.96	0.0135
REP(IRR)	4	0.95224444	8.35	0.0059	4	0.95224444	8.35	0.0059
FER	2	0.66223333	11.62	0.0043	2	0.66223333	11.62	0.0043
IRR*FER	2	0.07201111	1.26	0.3335	2	0.07201111	1.26	0.3335

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.28375556	1.19	0.3363

DEPENDENT VARIABLE: DW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	1867.82666667	209.75851852	5.02	0.0165	0.849641	21.3432
ERROR	8	334.08444444	41.76055556		ROOT MSE		DW MEAN
CORRECTED TOTAL	17	2221.91111111			6.46224075		30.27777778

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	9.97555556	0.24	0.6381	1	9.97555556	0.24	0.6381
REP(IRR)	4	640.18888889	3.83	0.0502	4	640.18888889	3.83	0.0502
FER	2	302.22111111	3.62	0.0760	2	302.22111111	3.62	0.0760
IRR*FER	2	935.44111111	11.20	0.0048	2	935.44111111	11.20	0.0048

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	9.97555556	0.06	0.8151

DEPENDENT VARIABLE: TNUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	2.43737688	0.27081965	6.09	0.0091	0.872565	21.2959
ERROR	8	0.35589310	0.04448664		ROOT MSE		TNUPT MEAN
CORRECTED TOTAL	17	2.79326997			0.21091856		0.99041667

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00396347	0.09	0.7729	1	0.00396347	0.09	0.7729
REP(IRR)	4	0.43330019	2.44	0.1322	4	0.43330019	2.44	0.1322
FER	2	0.70529543	7.93	0.0127	2	0.70529543	7.93	0.0127
IRR*FER	2	1.29481778	14.55	0.0022	2	1.29481778	14.55	0.0022

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00396347	0.04	0.8576

DEPENDENT VARIABLE: OXPRO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	15.60238747	1.73359861	5.65	0.0115	0.864055	24.0145
ERROR	8	2.45478209	0.30684776		ROOT MSE		OXPRO MEAN
CORRECTED TOTAL	17	18.05716955			0.55393841		2.30668515

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.06224345	0.20	0.6644	1	0.06224345	0.20	0.6644
REP(IRR)	4	2.51648640	2.05	0.1798	4	2.51648640	2.05	0.1798
FER	2	3.33236742	5.43	0.0324	2	3.33236742	5.43	0.0324
IRR*FER	2	9.69129020	15.79	0.0017	2	9.69129020	15.79	0.0017

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.06224345	0.10	0.7688

DEPENDENT VARIABLE: CX2PRO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	4.36409082	0.48489898	4.79	0.0190	0.843475	28.5883
ERROR	8	0.80982497	0.10122812		ROOT MSE		CX2PRO MEAN
CORRECTED TOTAL	17	5.17391579			0.31816367		1.11291475

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00692600	0.07	0.8003	1	0.00692600	0.07	0.8003
REP(IRR)	4	0.48485509	1.20	0.3824	4	0.48485509	1.20	0.3824
FER	2	1.93274965	9.55	0.0076	2	1.93274965	9.55	0.0076
IRR*FER	2	1.93956007	9.58	0.0075	2	1.93956007	9.58	0.0075

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00692600	0.06	0.8228

DEPENDENT VARIABLE: CX3PRO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	5.50206222	0.61134025	4.66	0.0205	0.839946	23.9774
ERROR	8	1.04843425	0.13105428		ROOT MSE		CX3PRO MEAN
CORRECTED TOTAL	17	6.55049646			0.36201420		1.50981650

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.01562576	0.12	0.7388	1	0.01562576	0.12	0.7388
REP(IRR)	4	1.34975279	2.57	0.1188	4	1.34975279	2.57	0.1188
FER	2	1.16762775	4.45	0.0501	2	1.16762775	4.45	0.0501
IRR*FER	2	2.96905592	11.33	0.0046	2	2.96905592	11.33	0.0046

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.01562576	0.05	0.8401

DEPENDENT VARIABLE: CX2_3PRO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	18.90977982	2.10108665	5.23	0.0146	0.854623	24.1771
ERROR	8	3.21667599	0.40208450		ROOT MSE		CX2_3PRO MEAN
CORRECTED TOTAL	17	22.12645581			0.63410133		2.62273125

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00174561	0.00	0.9491	1	0.00174561	0.00	0.9491
REP(IRR)	4	3.23770640	2.01	0.1855	4	3.23770640	2.01	0.1855
FER	2	5.98306294	7.44	0.0149	2	5.98306294	7.44	0.0149
IRR*FER	2	9.68726487	12.05	0.0039	2	9.68726487	[illegible]	[illegible]

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00174561	0.00	0.9652

DEPENDENT VARIABLE: CAUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	0.85215347	0.09468372	4.45	0.0236	0.833354	23.2040
ERROR	8	0.17035629	0.02129454		ROOT MSE		CAUPT MEAN
CORRECTED TOTAL	17	1.02250975			0.14592647		0.62888444

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.04905756	2.30	0.1675	1	0.04905756	2.30	0.1675
REP(IRR)	4	0.26793979	3.15	0.0786	4	0.26793979	3.15	0.0786
FER	2	0.10468341	2.46	0.1472	2	0.10468341	2.46	0.1472
IRR*FER	2	0.43047272	10.11	0.0065	2	0.43047272	10.11	0.0065

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.04905756	0.73	0.4404

DEPENDENT VARIABLE: MGUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	0.37010666	0.04112296	4.72	0.0198	0.841451	23.1473
ERROR	8	0.06973652	0.00871707		ROOT MSE		MGUPT MEAN
CORRECTED TOTAL	17	0.43984318			0.09336523		0.40335267

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.01297841	1.49	0.2571	1	0.01297841	1.49	0.2571
REP(IRR)	4	0.08778966	2.52	0.1240	4	0.08778966	2.52	0.1240
FER	2	0.05571107	3.20	0.0955	2	0.05571107	3.20	0.0955
IRR*FER	2	0.21362752	12.25	0.0037	2	0.21362752	12.25	0.0037

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.01297841	0.59	0.4848

DEPENDENT VARIABLE: KUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	4.47957869	0.49773097	7.37	0.0049	0.892342	20.1070
ERROR	8	0.54044568	0.06755571		ROOT MSE		KUPT MEAN
CORRECTED TOTAL	17	5.02002437			0.25991481		1.29265955

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00054795	0.01	0.9305	1	0.00054795	0.01	0.9305
REP(IRR)	4	1.18383632	4.38	0.0362	4	1.18383632	4.38	0.0362
FER	2	1.22892705	9.10	0.0097	2	1.22892705	9.10	0.0087
IRR*FER	2	2.06626737	15.29	0.0018	2	2.06626737	15.29	0.0018

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00054795	0.00	0.9677

DEPENDENT VARIABLE: NAUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	0.02433814	0.00270424	8.24	0.0034	0.902626	30.9688
ERROR	8	0.00262527	0.00032816		ROOT MSE		NAUPT MEAN
CORRECTED TOTAL	17	0.02696341			0.01811514		0.05849488

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.01176731	35.86	0.0003	1	0.01176731	35.86	0.0003
REP(IRR)	4	0.00396216	3.02	0.0859	4	0.00396216	3.02	0.0859
FER	2	0.00350351	5.34	0.0337	2	0.00350351	5.34	0.0337
IRR*FER	2	0.00510516	7.78	0.0133	2	0.00510516	7.78	0.0133

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.01176731	11.88	0.0261

DEPENDENT VARIABLE: CATUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	13.65301415	1.51700157	5.92	0.0099	0.869504	21.2342
ERROR	8	2.04905834	0.25613229		ROOT MSE		CATUPT MEAN
CORRECTED TOTAL	17	15.70207249			0.50609514		2.38339154

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00059142	0.00	0.9629	1	0.00059142	0.00	0.9629
REP(IRR)	4	3.79943764	3.71	0.0542	4	3.79943764	3.71	0.0542
FER	2	2.95894433	5.78	0.0280	2	2.95894433	5.78	0.0280
IRR*FER	2	6.89404076	13.46	0.0028	2	6.89404076	13.46	0.0028

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00059142	0.00	0.9813

DEPENDENT VARIABLE: PUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	0.03555146	0.00395016	8.41	0.0032	0.904418	24.6119
ERROR	8	0.00375722	0.00046965		ROOT MSE		PUPT MEAN
CORRECTED TOTAL	17	0.03930868			0.02167146		0.08805283

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.01758013	37.43	0.0003	1	0.01758013	37.43	0.0003
REP(IRR)	4	0.00840367	4.47	0.0343	4	0.00840367	4.47	0.0343
FER	2	0.00458399	4.88	0.0412	2	0.00458399	4.88	0.0412
IRR*FER	2	0.00498367	5.31	0.0341	2	0.00498367	5.31	0.0341

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.01758013	8.37	0.0444

DEPENDENT VARIABLE: SUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	0.04147030	0.00460781	4.24	0.0270	0.826755	24.2335
ERROR	8	0.00868763	0.00108595		ROOT MSE		SUPT MEAN
CORRECTED TOTAL	17	0.05015793			0.03295381		0.13598453

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00010905	0.10	0.7594	1	0.00010905	0.10	0.7594
REP(IRR)	4	0.01557094	3.58	0.0587	4	0.01557094	3.58	0.0587
FER	2	0.00532060	2.45	0.1479	2	0.00532060	2.45	0.1479
IRR*FER	2	0.02046971	9.42	0.0079	2	0.02046971	9.42	0.0079

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00010905	0.03	0.8752

DEPENDENT VARIABLE: CNO3UPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	0.17787183	0.01976354	1.87	0.1956	0.677602	55.6447
ERROR	8	0.08462983	0.01057873		ROOT MSE		CNO3UPT MEAN
CORRECTED TOTAL	17	0.26250166			0.10285294		0.18483855

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00000510	0.00	0.9830	1	0.00000510	0.00	0.9830
REP(IRR)	4	0.01668548	0.39	0.8076	4	0.01668548	0.39	0.8076
FER	2	0.07823272	3.70	0.0729	2	0.07823272	3.70	0.0729
IRR*FER	2	0.08294853	3.92	0.0650	2	0.08294853	3.92	0.0650

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00000510	0.00	0.9738

DEPENDENT VARIABLE: CLUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	0.01379198	0.00153244	4.01	0.0316	0.818662	24.0615
ERROR	8	0.00305500	0.00038187		ROOT MSE		CLUPT MEAN
CORRECTED TOTAL	17	0.01684698			0.01954161		0.08121512

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00037824	0.99	0.3488	1	0.00037824	0.99	0.3488
REP(IRR)	4	0.00632485	4.14	0.0416	4	0.00632485	4.14	0.0416
FER	2	0.00177535	2.32	0.1600	2	0.00177535	2.32	0.1600
IRR*FER	2	0.00531354	6.96	0.0178	2	0.00531354	6.96	0.0178

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.00037824	0.24	0.6504

DEPENDENT VARIABLE: CANUPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	0.59527955	0.06614217	2.83	0.0790	0.760856	31.2010
ERROR	8	0.18706022	0.02338253		ROOT MSE		CANUPT MEAN
CORRECTED TOTAL	17	0.78233977			0.15291346		0.49009104

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.02567099	1.10	0.3254	1	0.02567099	1.10	0.3254
REP(IRR)	4	0.06109292	0.65	0.6408	4	0.06109292	0.65	0.6408
FER	2	0.19208678	4.11	0.0593	2	0.19208678	4.11	0.0593
IRR*FER	2	0.31642886	6.77	0.0191	2	0.31642886	6.77	0.0191

TESTS OF HYPOTHESES USING THE TYPE III MS FOR REP(IRR) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
IRR	1	0.02567099	1.68	0.2646

Appendix C. Correlation matrix of oxalates and nitrate-N concentrations and various soil and climatic variables using data from non-irrigated plots of amaranth experiments at three sites.

	OX	OX2	OX3	OX2_3	NO3N	AIR1	AIR2	AIR3	AIR4	SOL1	SOL2	SOL3	SOL4
OX	1.00000	0.67794	-0.19297	0.63738	0.61909	-0.30971	-0.09179	-0.22195	-0.54985	-0.30301	-0.38563	-0.35736	0.53419
	0.0000	0.0001	0.3349	0.0004	0.0006	0.1158	0.6489	0.2659	0.0030	0.1244	0.0470	0.0673	0.0041
OX2	0.67794	1.00000	-0.41374	0.87035	0.38041	0.04745	0.19927	0.11443	-0.23811	0.05296	-0.01901	0.00691	0.35343
	0.0001	0.0000	0.0319	0.0001	0.0501	0.8142	0.3190	0.5698	0.2317	0.7931	0.9250	0.9727	0.0705
OX3	-0.19297	-0.41374	1.00000	0.08821	-0.26407	-0.06640	-0.03130	-0.05262	-0.09763	-0.06536	-0.07776	-0.07360	0.08718
	0.3349	0.0319	0.0000	0.6617	0.1832	0.7421	0.8769	0.7943	0.6281	0.7460	0.6999	0.7152	0.6654
OX2_3	0.63738	0.87035	0.08821	1.00000	0.27339	0.01600	0.20110	0.09674	-0.31333	0.02259	-0.06286	-0.03225	0.43386
	0.0004	0.0001	0.6617	0.0000	0.1677	0.9369	0.3145	0.6312	0.1115	0.9110	0.7554	0.8731	0.0238
NO3N	0.61908	0.38041	-0.26407	0.27339	1.00000	-0.49156	-0.25112	-0.39799	-0.68891	-0.48453	-0.56744	-0.53980	0.59974
	0.0006	0.0503	0.1832	0.1677	0.0000	0.0092	0.2064	0.0399	0.0001	0.0104	0.0020	0.0037	0.0010
AIR1	-0.30979	0.04745	-0.06640	0.01600	-0.49156	1.00000	0.91254	0.98410	0.70241	0.99990	0.98503	0.99441	-0.27611
	0.1159	0.8142	0.7421	0.9369	0.0092	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.1633
AIR2	-0.09178	0.19927	-0.03130	0.20110	-0.25112	0.91254	1.00000	0.97068	0.34987	0.91836	0.82836	0.86424	0.14113
	0.6489	0.3190	0.8768	0.3145	0.2064	0.0001	0.0000	0.0001	0.0736	0.0001	0.0001	0.0001	0.4825
AIR3	-0.22195	0.11443	-0.05262	0.09674	-0.39799	0.98410	0.97069	1.00000	0.56481	0.98656	0.93874	0.95984	-0.10099
	0.2659	0.5698	0.7943	0.6312	0.0398	0.0001	0.0001	0.0000	0.0022	0.0001	0.0001	0.0001	0.6162
AIR4	-0.54985	-0.23811	-0.09763	-0.31333	-0.68891	0.70241	0.34987	0.56481	1.00000	0.69205	0.81461	0.77365	-0.87804
	0.0030	0.2317	0.6281	0.1115	0.0001	0.0001	0.0736	0.0022	0.0000	0.0001	0.0001	0.0001	0.0001
SOL1	-0.30301	0.05296	-0.06536	0.02259	-0.43453	0.99990	0.91836	0.98656	0.69205	1.00000	0.98243	0.99278	-0.26219
	0.1244	0.7931	0.7460	0.9110	0.0104	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.1864
SOL2	-0.38563	-0.01901	-0.07776	-0.06286	-0.56744	0.98503	0.92836	0.93874	0.81461	0.98243	1.00000	0.99772	-0.41768
	0.0470	0.9250	0.6999	0.7554	0.0020	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0224
SOL3	-0.35736	0.00691	-0.07360	-0.03225	-0.53980	0.99441	0.86424	0.95984	0.77365	0.99278	0.99772	1.00000	-0.37607
	0.0673	0.9727	0.7152	0.8731	0.0037	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0532
SOL4	0.53419	0.35343	0.08718	0.43386	0.59974	-0.27611	0.14113	-0.10099	-0.87804	-0.26219	-0.41768	-0.37607	1.00000
	0.0041	0.0705	0.6654	0.0238	0.0010	0.1633	0.4826	0.6162	0.0001	0.1864	0.0224	0.0532	0.0000
SOL5	-0.55627	-0.31921	-0.09385	-0.40003	-0.65233	0.44999	0.04539	0.29420	0.95171	0.43703	0.59722	0.54178	-0.98257
	0.0026	0.1046	0.6415	0.0387	0.0002	0.0185	0.8221	0.1508	0.0001	0.0226	0.0010	0.0035	0.0001
SOL6	-0.55983	-0.30092	-0.09573	-0.38103	-0.66809	0.52053	0.12579	0.36059	0.97337	0.50813	0.65994	0.60779	-0.95439
	0.0024	0.1272	0.6348	0.0499	0.0001	0.0054	0.5319	0.0646	0.0001	0.0068	0.0002	0.0008	0.0001
SOL7	-0.55753	-0.31469	-0.09440	-0.39537	-0.65681	0.46847	0.06616	0.30409	0.95789	0.45565	0.61378	0.55915	-0.97849
	0.0025	0.1099	0.6395	0.0412	0.0002	0.0137	0.7430	0.1231	0.0001	0.0169	0.0007	0.0024	0.0001
SOL8	-0.27959	-0.36248	-0.03449	-0.41526	-0.21282	-0.44607	-0.77310	-0.59795	0.32371	-0.45896	-0.28509	-0.34906	-0.73704
	0.1578	0.0632	0.8644	0.0312	0.2865	0.0197	0.0001	0.0010	0.0995	0.0160	0.1495	0.0743	0.0001

	OX	OX2	OX3	OX2_3	NO3N	AIR1	AIR2	AIR3	AIR4	SOL1	SOL2	SOL3	SOL4
RH1	0.14315	-0.16761	0.03983	-0.16185	0.31011	-0.94683	-0.99560	-0.98393	-0.43608	-0.95139	-0.87719	-0.90757	-0.04773
	0.4763	0.4033	0.8436	0.4199	0.1154	0.0001	0.0001	0.0001	0.0230	0.0001	0.0001	0.0001	0.8129
RH2	0.33387	-0.02736	0.07007	0.00796	0.51623	-0.99862	-0.88981	-0.97341	-0.73981	-0.99776	-0.99272	-0.99858	0.32613
	0.0888	0.8922	0.7284	0.9685	0.0058	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0968
RH3	0.22550	-0.11189	0.05319	-0.09366	0.40187	-0.98530	-0.96899	-0.99998	-0.57050	-0.98767	-0.94110	-0.96175	0.10787
	0.2581	0.5784	0.7922	0.6422	0.0377	0.0001	0.0001	0.0001	0.0019	0.0001	0.0001	0.0001	0.5923
RH4	-0.20612	-0.34010	-0.02085	-0.38339	-0.11539	-0.57131	-0.85702	-0.70402	0.19287	-0.58312	-0.42126	-0.48145	-0.63108
	0.3023	0.0826	0.9178	0.0484	0.5666	0.0019	0.0001	0.0001	0.3612	0.0014	0.0286	0.0110	0.0004
RF	0.47443	0.11368	0.09000	0.17306	0.64668	-0.91141	-0.66340	-0.82382	-0.93308	-0.90537	-0.96871	-0.94977	0.64715
	0.0124	0.5724	0.6553	0.3880	0.0003	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003
SR	-0.51582	-0.17067	-0.09489	-0.23806	-0.67628	0.83428	0.53582	0.72308	0.97844	0.82622	0.91684	0.88784	-0.76026
	0.0059	0.3947	0.6378	0.2318	0.0001	0.0001	0.0040	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
WSP	-0.45647	-0.09234	-0.08766	-0.14845	-0.63190	0.93361	0.70542	0.85512	0.91080	0.92833	0.98140	0.96623	-0.60214
	0.0167	0.6469	0.6637	0.4599	0.0004	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0009
AIR1SQ	-0.32189	0.03747	-0.06825	0.00407	-0.50401	0.99966	0.90154	0.97912	0.72078	0.99918	0.98920	0.99683	-0.30119
	0.1016	0.8529	0.7352	0.9839	0.0074	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.1269
AIR2SQ	-0.09017	0.20023	-0.03103	0.20229	-0.24925	0.91134	1.00000	0.96997	0.34714	0.91720	0.82672	0.86277	0.14402
	0.6547	0.3167	0.8779	0.3116	0.2099	0.0001	0.0001	0.0001	0.0761	0.0001	0.0001	0.0001	0.4736
AIR3SQ	-0.23133	0.10770	-0.05412	0.08857	-0.40822	0.98718	0.96611	0.99983	0.57982	0.98939	0.94489	0.96481	-0.11913
	0.2457	0.5929	0.7886	0.6604	0.0345	0.0001	0.0001	0.0001	0.0015	0.0001	0.0001	0.0001	0.5538
AIR4SQ	-0.54851	-0.23444	-0.09759	-0.30929	-0.68899	0.71098	0.36119	0.57476	0.99993	0.70074	0.82157	0.78127	-0.87219
	0.0031	0.2392	0.6282	0.1164	0.0001	0.0001	0.0642	0.0017	0.0001	0.0001	0.0001	0.0001	0.0001
SOL1SQ	-0.31049	0.04688	-0.06651	0.01532	-0.49228	1.00000	0.91193	0.98383	0.70347	0.99987	0.98528	0.99456	-0.27754
	0.1150	0.8164	0.7417	0.9395	0.0091	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.1610
SOL2SQ	-0.39335	-0.02637	-0.07888	-0.07151	-0.57483	0.98154	0.81747	0.93196	0.82558	0.97867	0.99982	0.99625	-0.45484
	0.0424	0.8961	0.6957	0.7230	0.0017	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0171
SOL3SQ	-0.36516	-0.00010	-0.07476	-0.04054	-0.54752	0.99232	0.85493	0.95456	0.78508	0.99042	0.99879	0.99983	-0.39290
	0.0611	0.9996	0.7109	0.8409	0.0031	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0426
SOL4SQ	0.51685	0.36556	0.08287	0.44480	0.56684	-0.18864	0.22950	-0.01120	-0.83149	-0.17443	-0.35513	-0.29130	0.99595
	0.0058	0.0608	0.6811	0.0201	0.0021	0.3460	0.2495	0.9558	0.0001	0.3842	0.0691	0.1404	0.0001
SOL5SQ	-0.55759	-0.31444	-0.09442	-0.39512	-0.65704	0.46945	0.06727	0.30514	0.95821	0.45664	0.61465	0.56007	-0.97825
	0.0025	0.1102	0.6394	0.0414	0.0002	0.0135	0.7388	0.1217	0.0001	0.0166	0.0007	0.0024	0.0001
SOL6SQ	-0.56014	-0.29630	-0.09608	-0.37616	-0.67119	0.53675	0.14472	0.37833	0.97757	0.52449	0.67418	0.62285	-0.95915
	0.0024	0.1334	0.6335	0.0531	0.0001	0.0039	0.4714	0.0517	0.0001	0.0050	0.0001	0.0005	0.0001
SOL7SQ	-0.55856	-0.30999	-0.09490	-0.39051	-0.66103	0.48690	0.08708	0.32401	0.96371	0.47423	0.63020	0.57642	-0.97394
	0.0025	0.1156	0.6377	0.0440	0.0002	0.0100	0.6658	0.0992	0.0001	0.0125	0.0004	0.0017	0.0001

	OX	OX2	OX3	OX2_3	NO3N	AIR1	AIR2	AIR3	AIR4	SOL1	SOL2	SOL3	SOL4
SOL8SQ	-0.14853 0.4597	-0.31873 0.1051	-0.01040 0.9589	-0.35437 0.0697	-0.04120 0.8383	-0.65679 0.0002	-0.90775 0.0001	-0.78029 0.0001	0.07539 0.7086	-0.66762 0.0001	-0.51695 0.0059	-0.57348 0.0018	-0.54341 0.0034
RH1SQ	0.14095 0.4832	-0.16902 0.3994	0.03947 0.8450	-0.16358 0.4149	0.30761 0.1185	-0.94552 0.0001	-0.99599 0.0001	-0.99931 0.0001	-0.43242 0.0243	-0.95013 0.0001	-0.87523 0.0001	-0.90585 0.0001	-0.05193 0.7974
RH2SQ	0.32357 0.0997	-0.03606 0.8583	0.06851 0.7342	-0.00239 0.9906	0.50574 0.0071	-0.99956 0.0001	-0.99994 0.0001	-0.97836 0.0001	-0.72333 0.0001	-0.99902 0.0001	-0.98973 0.0001	-0.99712 0.0001	0.30465 0.1223
RH3SQ	0.21880 0.2729	-0.11668 0.5622	0.05212 0.7963	-0.09947 0.6216	0.39454 0.0417	-0.98299 0.0001	-0.97213 0.0001	-0.99998 0.0001	-0.55975 0.0024	-0.98554 0.0001	-0.93661 0.0001	-0.95310 0.0001	0.09491 0.6377
RH4SQ	-0.19386 0.3326	-0.33581 0.0868	-0.01861 0.9266	-0.37749 0.0522	-0.09944 0.6217	-0.59039 0.0012	-0.86886 0.0001	-0.72437 0.0001	0.15978 0.4260	-0.60200 0.0009	-0.44240 0.0208	-0.50186 0.0077	-0.61273 0.0007
RPSQ	0.45435 0.0173	0.08990 0.6556	0.08738 0.6647	0.14563 0.4686	0.63010 0.0004	-0.93593 0.0001	-0.71002 0.0001	-0.85848 0.0001	-0.90809 0.0001	-0.93074 0.0001	-0.98263 0.0001	-0.96789 0.0001	0.59693 0.0010
SRSQ	-0.52043 0.0054	-0.17809 0.3741	-0.09537 0.6361	-0.24645 0.2153	-0.67897 0.0001	0.82214 0.0001	0.51740 0.0057	0.70794 0.0001	0.98268 0.0001	0.81382 0.0001	0.90798 0.0001	0.87766 0.0001	-0.77415 0.0001
WSPSQ	-0.47533 0.0122	-0.11479 0.5686	-0.09011 0.6549	-0.17433 0.3845	-0.64739 0.0003	0.91017 0.0001	0.66114 0.0002	0.82211 0.0001	0.93416 0.0001	0.90408 0.0001	0.96796 0.0001	0.94882 0.0001	-0.64944 0.0002
SOLTN	0.55197 0.0028	0.26362 0.1840	0.05607 0.7812	0.31876 0.1051	0.70125 0.0001	-0.62687 0.0005	-0.25597 0.1975	-0.47962 0.0114	-0.99038 0.0001	-0.61563 0.0006	-0.75072 0.0001	-0.70497 0.0001	0.91535 0.0001
SOLCA	-0.59073 0.0012	-0.45051 0.0184	0.03514 0.8618	-0.47391 0.0125	-0.67100 0.0001	0.41147 0.0330	0.03161 0.8756	0.25558 0.1982	0.88748 0.0001	0.39928 0.0391	0.55027 0.0030	0.49796 0.0082	-0.92173 0.0001
SOLMG	-0.58684 0.0013	-0.28573 0.1485	-0.06871 0.7335	-0.34979 0.0737	-0.71647 0.0001	0.65603 0.0002	0.30281 0.1247	0.51711 0.0058	0.97567 0.0001	0.64551 0.0003	0.77092 0.0001	0.72875 0.0001	-0.87637 0.0001
SOLK	-0.45687 0.0166	-0.12517 0.5339	-0.19391 0.3325	-0.24184 0.2242	-0.63469 0.0004	0.69738 0.0001	0.36512 0.0611	0.56847 0.0020	0.96193 0.0001	0.68772 0.0001	0.80129 0.0001	0.76352 0.0001	-0.83002 0.0001
SOLNA	0.11486 0.5683	-0.00227 0.9910	-0.11349 0.5730	-0.06387 0.7516	-0.10900 0.5884	-0.00036 0.9986	-0.11320 0.5740	-0.04937 0.8068	0.19618 0.3267	-0.00434 0.9828	0.04723 0.8150	0.02879 0.8866	-0.26515 0.1813
SOLP	-0.21127 0.2901	-0.25243 0.2040	0.12131 0.5467	-0.21058 0.2917	-0.20243 0.3112	-0.11141 0.5801	-0.08220 0.6836	-0.10118 0.6156	-0.11213 0.5776	-0.11071 0.5825	-0.11795 0.5579	-0.11581 0.5651	0.07651 0.7045

	SOL5	SOL6	SOL7	SOL8	RH1	RH2	RH3	RH4	RP	SR	WSP	AIR1SQ	AIR2SQ
OX	-0.55627 0.0026	-0.55983 0.0024	-0.55753 0.0025	-0.27959 0.1578	0.14315 0.4763	0.33387 0.0888	0.22550 0.2581	-0.20612 0.3023	0.47443 0.0124	-0.51582 0.0059	-0.45647 0.0167	-0.32189 0.1016	-0.09017 0.6547
OX2	-0.31921 0.1046	-0.30092 0.1272	-0.31469 0.1099	-0.36248 0.0632	-0.16761 0.4033	-0.02736 0.8922	-0.11189 0.5784	-0.34010 0.0826	0.11368 0.5724	-0.17067 0.3947	-0.09234 0.6469	0.03747 0.8528	0.20023 0.3167
OX3	-0.09385 0.6415	-0.09573 0.6348	-0.09440 0.6395	-0.03449 0.8644	0.03983 0.8436	0.07007 0.7284	0.05319 0.7922	-0.02085 0.9178	0.09000 0.6553	-0.09489 0.6378	-0.08766 0.6637	-0.06825 0.7352	-0.03103 0.8779

	SOL5	SOL6	SOL7	SOL8	RH1	RH2	RH3	RH4	RF	SR	WSP	[illegible]	[illegible]
OX2_3	-0.40003 0.0387	-0.38103 0.0499	-0.39537 0.0412	-0.41526 0.0312	-0.16185 0.4199	0.00796 0.9685	-0.09366 0.6422	-0.38339 0.0484	0.17306 0.3880	-0.23806 0.2318	-0.14945 0.4599	0.00407 0.9839	0.20229 0.3115
NO3N	-0.65233 0.0002	-0.66809 0.0001	-0.65681 0.0002	-0.21282 0.2865	0.31011 0.1154	0.51623 0.0058	0.40187 0.0377	-0.11539 0.5666	0.64668 0.0003	-0.67628 0.0001	-0.63190 0.0004	-0.50401 0.0074	-0.24925 0.2093
AIR1	0.44999 0.0185	0.52053 0.0054	0.46947 0.0137	-0.44607 0.0197	-0.94683 0.0001	-0.99862 0.0001	-0.98530 0.0001	-0.57131 0.0019	-0.91141 0.0001	0.83428 0.0001	0.93361 0.0001	0.99966 0.0001	0.91134 0.0001
AIR2	0.04539 0.8221	0.12579 0.5319	0.06616 0.7430	-0.77310 0.0001	-0.99560 0.0001	-0.88981 0.0001	-0.96899 0.0001	-0.85702 0.0001	-0.66340 0.0002	0.53582 0.0040	0.70542 0.0001	0.90154 0.0001	1.00000 0.0001
AIR3	0.28420 0.1508	0.36059 0.0646	0.30409 0.1231	-0.59795 0.0010	-0.98893 0.0001	-0.97341 0.0001	-0.99998 0.0001	-0.70802 0.0001	-0.92382 0.0001	0.72308 0.0001	0.85512 0.0001	0.97912 0.0001	0.96997 0.0001
AIR4	0.95171 0.0001	0.97337 0.0001	0.95789 0.0001	0.32371 0.0995	-0.43609 0.0230	-0.73881 0.0001	-0.57050 0.0019	0.18287 0.3612	-0.93308 0.0001	0.97844 0.0001	0.91080 0.0001	0.72078 0.0001	0.34714 0.0761
SOL1	0.43703 0.0226	0.50813 0.0068	0.45565 0.0169	-0.45896 0.0160	-0.95139 0.0001	-0.99776 0.0001	-0.98767 0.0001	-0.59312 0.0014	-0.90537 0.0001	0.82622 0.0001	0.92833 0.0001	0.99918 0.0001	0.91720 0.0001
SOL2	0.59722 0.0010	0.65994 0.0002	0.61378 0.0007	-0.28508 0.1495	-0.87719 0.0001	-0.99272 0.0001	-0.94110 0.0001	-0.42126 0.0286	-0.96871 0.0001	0.91684 0.0001	0.98140 0.0001	0.98920 0.0001	0.82672 0.0001
SOL3	0.54178 0.0035	0.60779 0.0008	0.55915 0.0024	-0.34906 0.0743	-0.90757 0.0001	-0.99858 0.0001	-0.96175 0.0001	-0.48145 0.0110	-0.94977 0.0001	0.88784 0.0001	0.96623 0.0001	0.99683 0.0001	0.86277 0.0001
SOL4	-0.98257 0.0001	-0.96438 0.0001	-0.97848 0.0001	-0.73704 0.0001	-0.04778 0.8129	0.32619 0.0968	0.10787 0.5923	-0.63108 0.0004	0.64715 0.0003	-0.76026 0.0001	-0.60214 0.0009	-0.30114 0.1269	0.14402 0.4736
SOL5	1.00000 0.0000	0.99674 0.0001	0.99978 0.0001	0.59854 0.0010	-0.13876 0.4900	-0.49625 0.0085	-0.29082 0.1411	0.47586 0.0121	-0.77760 0.0001	0.86778 0.0001	0.74009 0.0001	0.47317 0.0127	0.04247 0.8334
SOL6	0.99674 0.0001	1.00000 0.0000	0.99821 0.0001	0.53200 0.0043	-0.21816 0.2743	-0.56464 0.0022	-0.36702 0.0597	0.40339 0.0369	-0.82577 0.0001	0.90502 0.0001	0.79189 0.0001	0.54267 0.0035	0.12289 0.5414
SOL7	0.99978 0.0001	0.99821 0.0001	1.00000 0.0000	0.58174 0.0015	-0.15933 0.4273	-0.51421 0.0061	-0.31067 0.1147	0.45745 0.0164	-0.79052 0.0001	0.87793 0.0001	0.75391 0.0001	0.49140 0.0092	0.06325 0.7540
SOL8	0.59854 0.0010	0.53200 0.0043	0.58174 0.0015	1.00000 0.0000	0.71029 0.0001	0.39846 0.0395	0.59240 0.0011	0.98940 0.0001	0.03826 0.8497	0.12130 0.5467	-0.09578 0.6346	-0.42252 0.0281	-0.77495 0.0001
RH1	-0.13876 0.4900	-0.21816 0.2743	-0.15933 0.4273	0.71029 0.0001	1.00000 0.0000	0.92864 0.0001	0.98788 0.0001	0.80499 0.0001	0.73057 0.0001	-0.61255 0.0007	-0.76871 0.0001	-0.93810 0.0001	-0.99533 0.0001
RH2	-0.49625 0.0085	-0.56464 0.0022	-0.51421 0.0061	0.39846 0.0395	0.92864 0.0001	1.00000 0.0000	0.97497 0.0001	0.52744 0.0047	0.93176 0.0001	-0.86208 0.0001	-0.95113 0.0001	-0.99965 0.0001	-0.88847 0.0001
RH3	-0.29082 0.1411	-0.36702 0.0597	-0.31067 0.1147	0.59240 0.0011	0.98788 0.0001	0.97497 0.0001	1.00000 0.0000	0.70312 0.0001	0.82772 0.0001	-0.72784 0.0001	-0.85868 0.0001	-0.98050 0.0001	-0.96827 0.0001
RH4	0.47586 0.0121	0.40339 0.0369	0.45745 0.0164	0.98940 0.0001	0.80499 0.0001	0.52744 0.0047	0.70312 0.0001	1.00000 0.0000	0.18297 0.3610	-0.02414 0.9049	-0.23933 0.2292	-0.54967 0.0030	-0.85852 0.0001

	SOL5	SOL6	SOL7	SOL8	RH1	RH2	RH3	RH4	RF	SR	WSP	AIR1SQ	AIR2SQ
RF	-0.77760	-0.32577	-0.79052	0.03826	0.73057	0.93176	0.92772	0.13297	1.00000	-0.98725	-0.99834	-0.92185	-0.66121
	0.0001	0.0001	0.0001	0.8497	0.0001	0.0001	0.0001	0.3610	0.0000	0.0001	0.0001	0.0001	0.0002
SR	0.86778	0.70502	0.87793	0.12130	-0.61255	-0.86209	-0.72784	-0.02414	-0.98725	1.00000	0.97643	0.84841	0.53336
	0.0001	0.0001	0.0001	0.5467	0.0007	0.0001	0.0001	0.9049	0.0001	0.0000	0.0001	0.0001	0.0042
WSP	0.74008	0.79189	0.75391	-0.09578	-0.76871	-0.95113	-0.85868	-0.23933	-0.99834	0.97643	1.00000	0.94266	0.70335
	0.0001	0.0001	0.0001	0.6346	0.0001	0.0001	0.0001	0.2292	0.0001	0.0001	0.0000	0.0001	0.0001
AIR1SQ	0.47317	0.54267	0.49140	-0.42252	-0.93810	-0.99965	-0.98050	-0.54967	-0.92185	0.84841	0.94266	1.00000	0.90027
	0.0127	0.0035	0.0092	0.0281	0.0001	0.0001	0.0001	0.0030	0.0001	0.0001	0.0001	0.0000	0.0001
AIR2SQ	0.04247	0.12289	0.06325	-0.77495	-0.93533	-0.88847	-0.96827	-0.85852	-0.66121	0.53336	0.70335	0.90027	1.00000
	0.8334	0.5414	0.7540	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0042	0.0001	0.0001	0.0000
AIR3SQ	0.30170	0.37759	0.32147	-0.58318	-0.98604	-0.97744	-0.99994	-0.69497	-0.83406	0.73560	0.86446	0.98267	0.96535
	0.1262	0.0522	0.1020	0.0014	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
AIR4SQ	0.94793	0.97052	0.95435	0.31223	-0.44694	-0.74692	-0.58040	0.17095	-0.93736	0.98087	0.91573	0.72912	0.35847
	0.0001	0.0001	0.0001	0.1128	0.0194	0.0001	0.0015	0.3939	0.0001	0.0001	0.0001	0.0001	0.0663
SOL1SQ	0.45131	0.52179	0.46978	-0.44474	-0.94636	-0.99870	-0.98505	-0.57010	-0.91202	0.83510	0.93414	0.99970	0.91073
	0.0181	0.0053	0.0134	0.0201	0.0001	0.0001	0.0001	0.0019	0.0001	0.0001	0.0001	0.0001	0.0001
SOL2SQ	0.61249	0.67423	0.62880	-0.26665	-0.86782	-0.99023	-0.93444	-0.40379	-0.97329	0.92433	0.98490	0.99620	0.81578
	0.0007	0.0001	0.0004	0.1788	0.0001	0.0001	0.0001	0.0367	0.0001	0.0001	0.0001	0.0001	0.0001
SOL3SQ	0.55702	0.62217	0.57418	-0.33191	-0.89976	-0.99744	-0.95660	-0.46538	-0.95532	0.89608	0.97077	0.99521	0.85341
	0.0026	0.0005	0.0017	0.0908	0.0001	0.0001	0.0001	0.0144	0.0001	0.0001	0.0001	0.0001	0.0001
SOL4SQ	-0.96189	-0.93671	-0.95599	-0.79478	-0.13733	0.23994	0.01811	-0.69822	0.57604	-0.69882	-0.52797	-0.21424	0.23234
	0.0001	0.0001	0.0001	0.0001	0.4946	0.2280	0.9285	0.0001	0.0017	0.0001	0.0047	0.2832	0.2435
SOL5SQ	0.99976	0.99827	1.00000	0.58084	-0.16043	-0.51516	-0.31172	0.45647	-0.79120	0.87846	0.75464	0.49237	0.06436
	0.0001	0.0001	0.0001	0.0015	0.4241	0.0060	0.1135	0.0167	0.0001	0.0001	0.0001	0.0091	0.7493
SOL6SQ	0.99502	0.99982	0.99688	0.51573	-0.23676	-0.58030	-0.38473	0.38584	-0.83639	0.91299	0.80342	0.55861	0.14183
	0.0001	0.0001	0.0001	0.0059	0.2344	0.0015	0.0475	0.0469	0.0001	0.0001	0.0001	0.0025	0.4804
SOL7SQ	0.99913	0.99924	0.99978	0.56455	-0.18001	-0.53209	-0.33054	0.43870	-0.80319	0.88778	0.76753	0.50957	0.08418
	0.0001	0.0001	0.0001	0.0022	0.3689	0.0043	0.0922	0.0221	0.0001	0.0001	0.0001	0.0066	0.6764
SOL8SQ	0.37787	0.30199	0.35852	0.96787	0.86447	0.61629	0.77595	0.99413	0.28831	-0.13220	-0.34301	-0.63686	-0.90897
	0.0520	0.1258	0.0663	0.0001	0.0001	0.0006	0.0001	0.0001	0.1447	0.5110	0.0798	0.0004	0.0001
RH1SQ	-0.13474	-0.21419	-0.15533	0.71314	0.99999	0.92713	0.98724	0.80739	0.72779	-0.60934	-0.76610	-0.93669	-0.99571
	0.5028	0.2834	0.4392	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0008	0.0001	0.0001	0.0001
RH2SQ	-0.47642	-0.54576	-0.49461	0.41918	0.93682	0.99974	0.97977	0.54659	0.92328	-0.85035	-0.94388	-0.99999	-0.99865
	0.0120	0.0032	0.0087	0.0295	0.0001	0.0001	0.0001	0.0032	0.0001	0.0001	0.0001	0.0001	0.0001
RH3SQ	-0.27833	-0.35487	-0.29825	0.60284	0.98981	0.97199	0.99992	0.71232	0.82034	-0.71894	-0.85193	-0.97786	-0.97144
	0.1598	0.0693	0.1308	0.0009	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

	SOL5	SOL6	SOL7	SOL8	RH1	RH2	RH3	RH4	RF	SR	WSP	AIR1SQ	AIR2SQ
RH4SQ	0.45511	0.38184	0.43649	0.98572	0.81867	0.54720	0.71959	0.99973	0.20596	-0.04756	-0.26201	-0.56910	-0.87030
	0.0171	0.0494	0.0228	0.0001	0.0001	0.0031	0.0001	0.0001	0.3027	0.8138	0.1869	0.0020	0.0001
RFSQ	-0.73568	-0.78790	-0.74961	0.10227	0.77286	0.95313	0.86201	0.24565	0.99794	-0.97501	-0.99999	-0.94481	-0.70795
	0.0001	0.0001	0.0001	0.6117	0.0001	0.0001	0.0001	0.2168	0.0001	0.0001	0.0001	0.0001	0.0001
SRSQ	0.87835	0.91403	0.88810	0.14279	-0.59528	-0.95089	-0.71280	-0.00246	-0.98357	0.99977	0.37153	0.83673	0.51430
	0.0001	0.0001	0.0001	0.4774	0.0011	0.0001	0.0001	0.9903	0.0001	0.0001	0.0001	0.0001	0.0060
WSPSQ	0.77949	0.82746	0.79236	-0.03525	-0.72851	-0.93066	-0.82603	-0.18001	-1.00000	0.98772	0.99816	0.92068	0.65895
	0.0001	0.0001	0.0001	0.8614	0.0001	0.0001	0.0001	0.3689	0.0001	0.0001	0.0001	0.0001	0.0002
SOLTN	-0.97222	-0.98616	-0.97642	-0.41204	0.34491	0.66657	0.48564	-0.27613	0.88934	-0.94906	-0.86214	-0.64685	-0.25315
	0.0001	0.0001	.0.0001	0.0327	0.0781	0.0001	0.0102	0.1633	0.0001	0.0001	0.0001	0.0003	0.2026
SOLCA	0.93602	0.93210	0.93559	0.56897	-0.11910	-0.45505	-0.26180	0.45499	-0.72101	0.80695	0.68541	0.43331	0.02983
	0.0001	0.0001	0.0001	0.0020	0.5541	0.0171	0.1871	0.0171	0.0001	0.0001	0.0001	0.0240	0.8863
SOLMG	0.94119	0.95912	0.94640	0.35477	-0.39844	-0.69310	-0.52282	0.21888	-0.89557	0.94613	0.87165	0.67471	0.30010
	0.0001	0.0001	0.0001	0.0694	0.0453	0.0001	0.0052	0.2727	0.0001	0.0001	0.0001	0.0001	0.1283
SOLK	0.90612	0.92932	0.91267	0.28254	-0.44692	-0.73124	-0.57383	0.14593	-0.90852	0.94749	0.88872	0.71447	0.36252
	0.0001	0.0001	0.0001	0.1533	0.0194	0.0001	0.0018	0.4677	0.0001	0.0001	0.0001	0.0001	0.0631
SOLNA	0.24630	0.23546	0.24365	0.24716	0.08912	-0.01413	0.04749	0.22671	-0.11324	0.15186	0.09855	0.00686	-0.11393
	0.2156	0.2371	0.2207	0.2139	0.6584	0.9442	0.8140	0.2555	0.5739	0.4496	0.6248	0.9729	0.5715
SOLP	-0.09264	-0.09863	-0.09424	0.00709	0.09017	0.11375	0.10164	0.02458	0.12113	-0.11919	-0.12107	-0.11261	-0.08194
	0.6458	0.6245	0.6401	0.9720	0.6547	0.5721	0.6139	0.9031	0.5473	0.5538	0.5475	0.5760	0.6845

	AIR3SQ	AIR4SQ	SOL1SQ	SOL2SQ	SOL3SQ	SOL4SQ	SOL5SQ	SOL6SQ	SOL7SQ	SOL8SQ	RH1SQ	RH2SQ	RH3SQ
OX	-0.23133	-0.54851	-0.31049	-0.39335	-0.36516	0.51685	-0.55759	-0.56014	-0.55856	-0.14853	0.14095	0.32357	0.21889
	0.2457	0.0031	0.1150	0.0424	0.0611	0.0058	0.0025	0.0024	0.0025	0.4597	0.4832	0.0997	0.2729
OX2	0.10770	-0.23444	0.04688	-0.02637	-0.00010	0.36556	-0.31444	-0.29630	-0.30999	-0.31873	-0.16902	-0.03606	-0.11669
	0.5929	0.2392	0.8164	0.8961	0.9996	0.0608	0.1102	0.1334	0.1156	0.1051	0.3994	0.8583	0.5622
OX3	-0.05412	-0.09759	-0.06651	-0.07888	-0.07476	0.08287	-0.09442	-0.09608	-0.09490	-0.01040	0.03947	0.06851	0.05212
	0.7886	0.6282	0.7417	0.6957	0.7109	0.6811	0.6394	0.6335	0.6377	0.9589	0.8450	0.7342	0.7963
OX2_3	0.09857	-0.30929	0.01532	-0.07151	-0.04054	0.44480	-0.39512	-0.37616	-0.39051	-0.35437	-0.16358	-0.00239	-0.09947
	0.6604	0.1164	0.9395	0.7230	0.8409	0.0201	0.0414	0.0531	0.0440	0.0697	0.4149	0.9906	0.6215
NO3N	-0.40822	-0.68899	-0.49228	-0.57483	-0.54752	0.56684	-0.65704	-0.67119	-0.66103	-0.04120	0.30761	0.50574	0.39454
	0.0345	0.0001	0.0091	0.0017	0.0031	0.0021	0.0002	0.0001	0.0002	0.8393	0.1185	0.0071	0.0417
AIR1	0.98718	0.71098	1.00000	0.98154	0.99232	-0.18864	0.46945	0.53675	0.48690	-0.65679	-0.94552	-0.99956	-0.98299
	0.0001	0.0001	0.0001	0.0001	0.0001	0.3460	0.0135	0.0039	0.0100	0.0002	0.0001	0.0001	0.0001
AIR2	0.96611	0.36119	0.91193	0.81747	0.85493	0.22950	0.06727	0.14472	0.08708	-0.90775	-0.99598	-0.89994	-0.97213
	0.0001	0.0642	0.0001	0.0001	0.0001	0.2495	0.7388	0.4714	0.6658	0.0001	0.0001	0.0001	0.0001

	AIR3SQ	AIR4SQ	SOL1SQ	SOL2SQ	SOL3SQ	SOL4SQ	SOL5SQ	SOL6SQ	SOL7SQ	SOL8SQ	RH1SQ	RH2SQ	RH3SQ
AIR3	0.99983 0.0001	0.57476 0.0017	0.98383 0.0001	0.93196 0.0001	0.95456 0.0001	-0.01120 0.9558	0.30514 0.1217	0.37833 0.0517	0.32401 0.0992	-0.78029 0.0001	-0.98331 0.0001	-0.97336 0.0001	-0.99993 0.0001
AIR4	0.57982 0.0015	0.99993 0.0001	0.70347 0.0001	0.82558 0.0001	0.78509 0.0001	-0.83149 0.0001	0.95821 0.0001	0.97757 0.0001	0.96371 0.0001	0.07539 0.7036	-0.43242 0.0243	-0.72333 0.0001	-0.55975 0.0024
SOL1	0.98939 0.0001	0.70074 0.0001	0.99987 0.0001	0.97867 0.0001	0.99042 0.0001	-0.17443 0.3842	0.45664 0.0166	0.52449 0.0050	0.47423 0.0125	-0.66762 0.0001	-0.95013 0.0001	-0.99902 0.0001	-0.98551 0.0001
SOL2	0.94499 0.0001	0.92157 0.0001	0.98529 0.0001	0.99982 0.0001	0.99979 0.0001	-0.35513 0.0691	0.61465 0.0007	0.67418 0.0001	0.63020 0.0004	-0.51695 0.0058	-0.87523 0.0001	-0.98973 0.0001	-0.93661 0.0001
SOL3	0.96481 0.0001	0.78127 0.0001	0.99456 0.0001	0.99625 0.0001	0.99983 0.0001	-0.29130 0.1404	0.56007 0.0024	0.62285 0.0005	0.57642 0.0017	-0.57348 0.0018	-0.90585 0.0001	-0.99712 0.0001	-0.95813 0.0001
SOL4	-0.11919 0.5538	-0.87219 0.0001	-0.27754 0.1610	-0.45484 0.0171	-0.39290 0.0426	0.99596 0.0001	-0.97825 0.0001	-0.95915 0.0001	-0.97394 0.0001	-0.54341 0.0034	-0.05193 0.7974	0.30465 0.1223	0.09491 0.6377
SOL5	0.30170 0.1262	0.94793 0.0001	0.45131 0.0181	0.61248 0.0007	0.55702 0.0026	-0.96189 0.0001	0.99976 0.0001	0.99502 0.0001	0.99913 0.0001	0.37787 0.0520	-0.13474 0.5028	-0.47642 0.0120	-0.27833 0.1598
SOL6	0.37759 0.0522	0.97052 0.0001	0.52179 0.0053	0.67423 0.0001	0.62217 0.0005	-0.93671 0.0001	0.99827 0.0001	0.99982 0.0001	0.99924 0.0001	0.30199 0.1258	-0.21419 0.2834	-0.54576 0.0032	-0.35497 0.0693
SOL7	0.32147 0.1020	0.95435 0.0001	0.46978 0.0134	0.62880 0.0004	0.57418 0.0017	-0.95599 0.0001	1.00000 0.0001	0.99688 0.0001	0.99978 0.0001	0.35852 0.0663	-0.15533 0.4392	-0.49461 0.0087	-0.29825 0.1308
SOL8	-0.58318 0.0014	0.31223 0.1128	-0.44474 0.0201	-0.26665 0.1788	-0.33191 0.0908	-0.79478 0.0001	0.58084 0.0015	0.51573 0.0059	0.56455 0.0022	0.96787 0.0001	0.71314 0.0001	0.41918 0.0295	0.60284 0.0009
RH1	-0.98604 0.0001	-0.44694 0.0194	-0.94636 0.0001	-0.86782 0.0001	-0.89976 0.0001	-0.13733 0.4946	-0.16043 0.4241	-0.23676 0.2344	-0.18001 0.3689	0.86447 0.0001	0.99999 0.0001	0.93682 0.0001	0.99931 0.0001
RH2	-0.97744 0.0001	-0.74692 0.0001	-0.99870 0.0001	-0.99023 0.0001	-0.99744 0.0001	0.23994 0.2280	-0.51516 0.0060	-0.58030 0.0015	-0.53209 0.0043	0.61629 0.0006	0.92713 0.0001	0.99974 0.0001	0.97193 0.0001
RH3	-0.99994 0.0001	-0.58040 0.0015	-0.98505 0.0001	-0.93444 0.0001	-0.95660 0.0001	0.01811 0.9285	-0.31172 0.1135	-0.38473 0.0475	-0.33054 0.0922	0.77595 0.0001	0.98724 0.0001	0.97977 0.0001	0.99992 0.0001
RH4	-0.69497 0.0001	0.17095 0.3939	-0.57010 0.0019	-0.40379 0.0367	-0.46538 0.0144	-0.69822 0.0001	0.45647 0.0167	0.38584 0.0468	0.43870 0.0221	0.99413 0.0001	0.80739 0.0001	0.54659 0.0032	0.71232 0.0001
RF	-0.83406 0.0001	-0.93736 0.0001	-0.91202 0.0001	-0.97329 0.0001	-0.95532 0.0001	0.57604 0.0017	-0.79120 0.0001	-0.83639 0.0001	-0.80319 0.0001	0.28831 0.1447	0.72779 0.0001	0.92328 0.0001	0.82034 0.0001
SR	0.73560 0.0001	0.98087 0.0001	0.83510 0.0001	0.92433 0.0001	0.89608 0.0001	-0.69882 0.0001	0.87846 0.0001	0.91299 0.0001	0.88778 0.0001	-0.13220 0.5110	-0.60934 0.0008	-0.85035 0.0001	-0.71894 0.0001
WSP	0.86446 0.0001	0.91573 0.0001	0.93814 0.0001	0.98490 0.0001	0.97077 0.0001	-0.52797 0.0047	0.75464 0.0001	0.80342 0.0001	0.76753 0.0001	-0.34301 0.0798	-0.76610 0.0001	-0.94388 0.0001	-0.85193 0.0001
AIR1SQ	0.98267 0.0001	0.72912 0.0001	0.99970 0.0001	0.98620 0.0001	0.99521 0.0001	-0.21424 0.2832	0.49237 0.0091	0.55861 0.0025	0.50957 0.0066	-0.63686 0.0004	-0.93669 0.0001	-0.99999 0.0001	-0.97785 0.0001

	AIR3SQ	AIR4SQ	SOL1SQ	SOL2SQ	SOL3SQ	SOL4SQ	SOL5SQ	SOL6SQ	SOL7SQ	SOL8SQ	BH1SQ	BH2SQ	BH3SQ
AIR2SQ	0.96536	0.35847	0.91073	0.81578	0.85341	0.23234	0.06436	0.14183	0.08410	-0.90897	-0.99571	-0.89866	-0.97144
	0.0001	0.0663	0.0001	0.0001	0.0001	0.2435	0.7498	0.4804	0.6764	0.0001	0.0001	0.0001	0.0001
AIR3SQ	1.00000	0.58964	0.98694	0.93844	0.95985	-0.02950	0.32252	0.39521	0.34127	-0.76872	-0.98536	-0.98198	-0.99970
	0.0000	0.0012	0.0001	0.0001	0.0001	0.8839	0.1008	0.0413	0.0815	0.0001	0.0001	0.0001	0.0001
AIR4SQ	0.58964	1.00000	0.71202	0.83235	0.79252	-0.82471	0.95468	0.97495	0.96040	0.06331	-0.44331	-0.73163	-0.56974
	0.0012	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.7537	0.0206	0.0001	0.0019
SOL1SQ	0.98694	0.71202	1.00000	0.98182	0.99250	-0.19010	0.47076	0.53800	0.48820	-0.65567	-0.94504	-0.99960	-0.98272
	0.0001	0.0001	0.0000	0.0001	0.0001	0.3422	0.0132	0.0038	0.0098	0.0002	0.0001	0.0001	0.0001
SOL2SQ	0.93844	0.83235	0.98182	1.00000	0.99766	-0.37299	0.62966	0.68821	0.64497	-0.50044	-0.86580	-0.98681	-0.92972
	0.0001	0.0001	0.0001	0.0000	0.0001	0.0553	0.0004	0.0001	0.0003	0.0079	0.0001	0.0001	0.0001
SOL3SQ	0.95985	0.79252	0.99250	0.99766	1.00000	-0.30869	0.57509	0.63701	0.59123	-0.55845	-0.89798	-0.99557	-0.95272
	0.0001	0.0001	0.0001	0.0001	0.0000	0.1172	0.0017	0.0004	0.0012	0.0025	0.0001	0.0001	0.0001
SOL4SQ	-0.02950	-0.82471	-0.19010	-0.37299	-0.30869	1.00000	-0.95566	-0.92985	-0.94962	-0.61664	-0.14135	0.21784	0.00508
	0.8839	0.0001	0.3422	0.0553	0.1172	0.0000	0.0001	0.0001	0.0001	0.0006	0.4819	0.2750	0.9799
SOL5SQ	0.32252	0.95468	0.47076	0.62966	0.57509	-0.95566	1.00000	0.99697	0.99980	0.35749	-0.15642	-0.49557	-0.29931
	0.1008	0.0001	0.0132	0.0004	0.0017	0.0001	0.0000	0.0001	0.0001	0.0671	0.4359	0.0086	0.1293
SOL6SQ	0.39521	0.97495	0.53800	0.68821	0.63701	-0.92985	0.99697	1.00000	0.99832	0.28372	-0.23282	-0.56167	-0.37266
	0.0413	0.0001	0.0038	0.0001	0.0004	0.0001	0.0001	0.0000	0.0001	0.1515	0.2425	0.0023	0.0556
SOL7SQ	0.34127	0.96040	0.48820	0.64497	0.59123	-0.94962	0.99980	0.99832	1.00000	0.33886	-0.17602	-0.51273	-0.31821
	0.0815	0.0001	0.0098	0.0003	0.0012	0.0001	0.0001	0.0001	0.0000	0.0838	0.3798	0.0062	0.1057
SOL8SQ	-0.76872	0.06331	-0.65567	-0.50044	-0.55845	-0.61664	0.35749	0.28372	0.33886	1.00000	0.86650	0.63401	0.78410
	0.0001	0.7537	0.0002	0.0079	0.0025	0.0006	0.0671	0.1515	0.0838	0.0000	0.0001	0.0004	0.0001
BH1SQ	-0.98536	-0.44331	-0.94504	-0.86580	-0.89798	-0.14135	-0.15642	-0.23282	-0.17602	0.86650	1.00000	0.93539	0.98923
	0.0001	0.0206	0.0001	0.0001	0.0001	0.4819	0.4359	0.2425	0.3798	0.0001	0.0000	0.0001	0.0001
BH2SQ	-0.98198	-0.73163	-0.99960	-0.98681	-0.99557	0.21784	-0.49557	-0.56167	-0.51273	0.63401	0.93539	1.00000	0.97708
	0.0001	0.0001	0.0001	0.0001	0.0001	0.2750	0.0086	0.0023	0.0062	0.0004	0.0001	0.0000	0.0001
BH3SQ	-0.99970	-0.56974	-0.98272	-0.92972	-0.95272	0.00508	-0.29931	-0.37266	-0.31821	0.78410	0.98923	0.97708	1.00000
	0.0001	0.0019	0.0001	0.0001	0.0001	0.9799	0.1293	0.0556	0.1057	0.0001	0.0001	0.0001	0.0000
BH4SQ	-0.71163	0.14782	-0.58919	-0.42512	-0.48600	-0.68125	0.43549	0.36411	0.41752	0.99639	0.82099	0.56606	0.72853
	0.0001	0.4619	0.0012	0.0271	0.0102	0.0001	0.0232	0.0619	0.0302	0.0001	0.0001	0.0021	0.0001
BPSQ	-0.86772	-0.91309	-0.93645	-0.98601	-0.97231	0.52243	-0.75035	-0.79952	-0.76334	0.34912	0.77028	0.94601	0.85533
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0052	0.0001	0.0001	0.0001	0.0743	0.0001	0.0001	0.0001
SBSQ	0.72074	0.98485	0.82298	0.91584	0.88625	-0.71416	0.88861	0.92161	0.89755	-0.11068	-0.59201	-0.83875	-0.70360
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.5826	0.0012	0.0001	0.0001
WSPSQ	0.83239	0.93841	0.91078	0.97259	0.95443	-0.57850	0.79304	0.83804	0.80498	-0.28542	-0.72572	-0.92212	-0.81861
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0016	0.0001	0.0001	0.0001	0.1490	0.0001	0.0001	0.0001

	AIR3SQ	AIR4SQ	SOL1SQ	SOL2SQ	SOL3SQ	SOL4SQ	SOL5SQ	SOL6SQ	SOL7SQ	SOL8SQ	RH1SQ	RH2SQ	RH3SQ
SOLTN	-0.49550 0.0086	-0.98913 0.0001	-0.62801 0.0005	-0.76310 0.0001	-0.71766 0.0001	0.87718 0.0001	-0.97664 0.0001	-0.98352 0.0001	-0.98023 0.0001	-0.17103 0.3937	0.34112 0.0816	0.64963 0.0002	0.47423 0.0124
SOLCA	0.27201 0.1699	0.88381 0.0001	0.41272 0.0324	0.56469 0.0022	0.51234 0.0063	-0.90332 0.0001	0.93556 0.0001	0.93028 0.0001	0.93475 0.0001	0.36377 0.0621	-0.11533 0.5669	-0.43636 0.0229	-0.25006 0.2090
SOLMG	0.53218 0.0043	0.97510 0.0001	0.65711 0.0002	0.78227 0.0001	0.74049 0.0001	-0.83412 0.0001	0.94667 0.0001	0.96245 0.0001	0.95124 0.0001	0.11459 0.5693	-0.38480 0.0475	-0.67731 0.0001	-0.51293 0.0063
SOLK	0.58259 0.0014	0.96223 0.0001	0.69836 0.0001	0.81136 0.0001	0.77408 0.0001	-0.78290 0.0001	0.91301 0.0001	0.93393 0.0001	0.91888 0.0001	0.04211 0.8348	-0.44346 0.0205	-0.71685 0.0001	-0.56371 0.0022
SOLNA	-0.04439 0.9260	0.19382 0.3327	0.00005 0.9998	0.05243 0.7951	0.03379 0.8671	-0.27096 0.1716	0.24351 0.2210	0.23266 0.2429	0.24088 0.2261	0.20834 0.2970	0.09018 0.6546	-0.00787 0.9689	0.05133 0.8009
SOLP	-0.10239 0.6113	-0.11268 0.5758	-0.11148 0.5799	-0.11845 0.5562	-0.11644 0.5630	0.06776 0.7370	-0.09433 0.6398	-0.09996 0.6198	-0.09582 0.6345	0.03728 0.8535	0.08984 0.6559	0.11278 0.5754	0.10077 0.6179

	RH4SQ	RPSQ	SRSQ	WSPSQ	SOLTN	SOLCA	SOLMG	SOLK	SOLNA	SOLP
OX	-0.19386 0.3326	0.45435 0.0173	-0.52043 0.0054	-0.47533 0.0122	0.55197 0.0028	-0.59073 0.0012	-0.58684 0.0013	-0.45687 0.0166	0.11486 0.5693	-0.21127 0.2901
OX2	-0.33581 0.0868	0.08990 0.6556	-0.17809 0.3741	-0.11479 0.5686	0.26362 0.1840	-0.45051 0.0184	-0.28573 0.1485	-0.12517 0.5339	-0.00227 0.9910	-0.25243 0.2040
OX3	-0.01861 0.9266	0.08738 0.6647	-0.09537 0.6361	-0.09011 0.6549	0.05607 0.7812	0.03514 0.8618	-0.06871 0.7335	-0.19391 0.3325	-0.11349 0.5730	0.12131 0.5467
OX2_3	-0.37749 0.0522	0.14563 0.4686	-0.24645 0.2153	-0.17433 0.3845	0.31876 0.1051	-0.47391 0.0125	-0.34979 0.0737	-0.24184 0.2242	-0.06387 0.7516	-0.21058 0.2917
NO3N	-0.09944 0.6217	0.63010 0.0004	-0.67897 0.0001	-0.64739 0.0003	0.70125 0.0001	-0.67100 0.0001	-0.71647 0.0001	-0.63468 0.0004	-0.10900 0.5884	-0.20243 0.3112
AIR1	-0.59039 0.0012	-0.93593 0.0001	0.82214 0.0001	0.91017 0.0001	-0.62687 0.0005	0.41147 0.0330	0.65603 0.0002	0.69738 0.0001	-0.00036 0.9986	-0.11141 0.5801
AIR2	-0.86886 0.0001	-0.71002 0.0001	0.51740 0.0057	0.66114 0.0002	-0.25597 0.1975	0.03161 0.8756	0.30281 0.1247	0.36512 0.0611	-0.11320 0.5740	-0.08220 0.6836
AIR3	-0.72437 0.0001	-0.85848 0.0001	0.70794 0.0001	0.82211 0.0001	-0.47962 0.0114	0.25558 0.1982	0.51711 0.0059	0.56847 0.0020	-0.04937 0.8068	-0.10118 0.6156
AIR4	0.15978 0.4260	-0.90809 0.0001	0.98268 0.0001	0.93416 0.0001	-0.99038 0.0001	0.88748 0.0001	0.97567 0.0001	0.96193 0.0001	0.19618 0.3267	-0.11213 0.5776
SOL1	-0.60200 0.0009	-0.93074 0.0001	0.81382 0.0001	0.90408 0.0001	-0.61563 0.0006	0.39928 0.0391	0.64551 0.0003	0.68772 0.0001	-0.00434 0.9828	-0.11071 0.5825
SOL2	-0.44240 0.0208	-0.98263 0.0001	0.90798 0.0001	0.96796 0.0001	-0.75072 0.0001	0.55027 0.0030	0.77092 0.0001	0.80129 0.0001	0.04723 0.8150	-0.11795 0.5579

	BH4SQ	RFSQ	SBSQ	WSPSQ	SOLTN	SOLCA	SOLMG	SOLK	SOLNA	SOLP
SOL3	-0.50186	-0.96789	0.87766	0.94882	-0.70497	0.49796	0.72875	0.76352	0.02879	-0.11581
	0.0077	0.0001	0.0001	0.0001	0.0001	0.0092	0.0001	0.0001	0.8866	0.5651
SOL4	-0.61273	0.59693	-0.77416	-0.64944	0.91585	-0.92173	-0.87637	-0.83002	-0.26515	0.07651
	0.0007	0.0010	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.1813	0.7045
SOL5	0.45511	-0.73568	0.87835	0.77949	-0.97222	0.93602	0.94119	0.90612	0.24630	-0.09264
	0.0171	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.2156	0.6458
SOL6	0.38184	-0.78790	0.91403	0.82746	-0.98616	0.93210	0.95912	0.92932	0.23546	-0.09363
	0.0494	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.2371	0.6245
SOL7	0.43649	-0.74961	0.88810	0.79236	-0.97642	0.93559	0.94640	0.91267	0.24365	-0.09424
	0.0228	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.2207	0.6401
SOL8	0.98572	0.10227	0.14279	-0.03525	-0.41204	0.56897	0.35477	0.28254	0.24716	0.00719
	0.0001	0.6117	0.4774	0.8614	0.0327	0.0020	0.0694	0.1533	0.2139	0.9720
BH1	0.81867	0.77286	-0.59528	-0.72851	0.34491	-0.11910	-0.38844	-0.44692	0.08912	0.09017
	0.0001	0.0001	0.0011	0.0001	0.0781	0.5541	0.0453	0.0194	0.6584	0.6547
BH2	0.54720	0.95313	-0.85089	-0.93066	0.66657	-0.45505	-0.69310	-0.73124	-0.01413	0.11375
	0.0031	0.0001	0.0001	0.0001	0.0001	0.0171	0.0001	0.0001	0.9442	0.5721
BH3	0.71959	0.86201	-0.71280	-0.82603	0.49564	-0.26180	-0.52282	-0.57383	0.04749	0.10164
	0.0001	0.0001	0.0001	0.0001	0.0102	0.1871	0.0052	0.0018	0.8140	0.6139
BH4	0.99973	0.24565	-0.00246	-0.18001	-0.27613	0.45499	0.21888	0.14593	0.22671	0.02458
	0.0001	0.2168	0.9903	0.3689	0.1633	0.0171	0.2727	0.4677	0.2555	0.9031
RF	0.20596	0.99794	-0.98357	-1.00000	0.98934	-0.72101	-0.89557	-0.90852	-0.11324	0.12113
	0.3027	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.5739	0.5473
SB	-0.04756	-0.97501	0.99977	0.98772	-0.94906	0.80685	0.94613	0.94749	0.15186	-0.11919
	0.8138	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.4496	0.5538
WSP	-0.26201	-0.99998	0.97153	0.99816	-0.86214	0.68541	0.87165	0.88872	0.09855	-0.12107
	0.1868	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.6248	0.5475
AIR1SQ	-0.56910	-0.94481	0.83673	0.92068	-0.64685	0.43331	0.67471	0.71447	0.00686	-0.11251
	0.0020	0.0001	0.0001	0.0001	0.0003	0.0240	0.0001	0.0001	0.9729	0.5760
AIR2SQ	-0.87030	-0.70796	0.51490	0.65895	-0.25316	0.02888	0.30010	0.36252	-0.11393	-0.08194
	0.0001	0.0001	0.0060	0.0002	0.2026	0.8863	0.1283	0.0631	0.5715	0.6845
AIR3SQ	-0.71163	-0.86772	0.72074	0.83239	-0.49550	0.27201	0.53218	0.58259	-0.04439	-0.10238
	0.0001	0.0001	0.0001	0.0001	0.0086	0.1699	0.0043	0.0014	0.8260	0.6113
AIR4SQ	0.14782	-0.91309	0.98485	0.93841	-0.98913	0.88381	0.97510	0.96223	0.19382	-0.11268
	0.4619	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.3327	0.5758
SOL1SQ	-0.58919	-0.93645	0.82298	0.91078	-0.62801	0.41272	0.65711	0.69836	0.00005	-0.11148
	0.0012	0.0001	0.0001	0.0001	0.0005	0.0324	0.0002	0.0001	0.9998	0.5799

	RH4SQ	RFSQ	SBSQ	WSPSQ	SOLTN	SOLCA	SOLMG	SOLK	SOLNA	SOLP
SOL2SQ	-0.42512	-0.98601	0.91584	0.97259	-0.76310	0.56469	0.78227	0.91136	0.05243	-0.11845
	0.0271	0.0001	0.0001	0.0001	0.0001	0.0022	0.0001	0.0001	0.7951	0.5562
SOL3SQ	-0.48600	-0.97231	0.88625	0.95443	-0.71766	0.51234	0.74049	0.77408	0.03379	-0.11644
	0.0102	0.0001	0.0001	0.0001	0.0001	0.0063	0.0001	0.0001	0.8671	0.5630
SOL4SQ	-0.68125	0.52243	-0.71416	-0.57850	0.87718	-0.90332	-0.83412	-0.78290	-0.27096	0.05776
	0.0001	0.0052	0.0001	0.0016	0.0001	0.0001	0.0001	0.0001	0.1716	0.7370
SOL5SQ	0.43549	-0.75035	0.88861	0.79304	-0.97664	0.93556	0.94667	0.91301	0.24351	-0.09433
	0.0232	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.2210	0.6398
SOL6SQ	0.36411	-0.79952	0.92161	0.83804	-0.98852	0.93028	0.96245	0.93393	0.23266	-0.09936
	0.0619	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.2429	0.6198
SOL7SQ	0.41752	-0.76334	0.89755	0.80498	-0.99023	0.93475	0.95124	0.91888	0.24088	-0.09592
	0.0302	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.2261	0.6345
SOL8SQ	0.99639	0.34912	-0.11068	-0.28542	-0.17103	0.36377	0.11459	0.04211	0.20834	0.03728
	0.0001	0.0743	0.5826	0.1490	0.3937	0.0621	0.5693	0.8348	0.2970	0.8535
RH1SQ	0.82099	0.77028	-0.59201	-0.72572	0.34112	-0.11533	-0.38480	-0.44346	0.09018	0.08984
	0.0001	0.0001	0.0012	0.0001	0.0816	0.5668	0.0475	0.0205	0.6546	0.6559
RH2SQ	0.56606	0.94601	-0.83875	-0.92212	0.64963	-0.43636	-0.67731	-0.71685	-0.00787	0.11278
	0.0021	0.0001	0.0001	0.0001	0.0002	0.0229	0.0001	0.0001	0.9689	0.5754
RH3SQ	0.72858	0.85533	-0.70360	-0.81961	0.47428	-0.25006	-0.51203	-0.56371	0.05103	0.10077
	0.0001	0.0001	0.0001	0.0001	0.0124	0.2084	0.0063	0.0022	0.8004	0.6170
RH4SQ	1.00000	0.26830	-0.02590	-0.20302	-0.25365	0.43569	0.19652	0.12360	0.22296	0.02736
	0.0000	0.1760	0.8980	0.3098	0.2017	0.0231	0.3259	0.5391	0.2636	0.8923
RFSQ	0.26830	1.00000	-0.96996	-0.99774	0.85888	-0.68124	-0.86876	-0.88629	-0.09687	0.12103
	0.1760	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.6308	0.5476
SBSQ	-0.02590	-0.96996	1.00000	0.98410	-0.95532	0.81695	0.95115	0.95092	0.15682	-0.11869
	0.8980	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.4347	0.5554
WSPSQ	-0.20302	-0.99774	0.98410	1.00000	-0.89068	0.72280	0.89674	0.90948	0.11400	-0.12112
	0.3098	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.5713	0.5473
SOLTN	-0.25365	0.85888	-0.95532	-0.89068	1.00000	-0.90545	-0.96661	-0.94315	-0.20984	0.07577
	0.2017	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.2935	0.7072
SOLCA	0.43569	-0.68124	0.81695	0.72280	-0.90545	1.00000	0.92546	0.87219	0.23674	0.04938
	0.0231	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.2345	0.8068
SOLMG	0.19652	-0.86876	0.95115	0.89674	-0.96661	0.92546	1.00000	0.96664	0.19984	-0.07687
	0.3259	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.3176	0.7031
SOLK	0.12360	-0.88629	0.95092	0.90948	-0.94315	0.87219	0.96664	1.00000	0.26078	-0.12551
	0.5391	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.1889	0.5328
SOLNA	0.22296	-0.09687	0.15682	0.11400	-0.20984	0.23674	0.19984	0.26078	1.00000	0.02697
	0.2636	0.6308	0.4347	0.5713	0.2935	0.2345	0.3176	0.1889	0.0000	0.8938
SOLP	0.02736	0.12103	-0.11869	-0.12112	0.07577	0.04938	-0.07687	-0.12551	0.02697	1.00000
	0.8923	0.5476	0.5554	0.5473	0.7072	0.8068	0.7031	0.5328	0.8938	0.0000

Appendix D. Correlation matrix of oxalates, nitrate-N concentrations and various soil and climatic variables using data from irrigated plots of amaranth experiments at three sites.

	OX	OX2	OX3	OX2_3	NO3N	AIR1	AIR2	AIR3	AIR4	SOL1	SOL2	SOL3	SOL4
OX	1.00000	0.46623	0.23006	0.66985	0.69839	-0.12417	0.44259	0.12806	-0.48796	0.04715	-0.22699	-0.09470	0.58620
	0.0000	0.0216	0.2795	0.0003	0.0001	0.5543	0.0267	0.5418	0.0133	0.8229	0.2752	0.6525	0.0021
	25	24	24	24	24	25	25	25	25	25	25	25	25
OX2	0.46623	1.00000	-0.44709	0.58075	0.37898	0.30759	0.60648	0.50694	-0.14544	0.45231	0.20264	0.33517	0.47490
	0.0216	0.0000	0.0285	0.0029	0.0745	0.1437	0.0017	0.0115	0.4977	0.0255	0.3423	0.1094	0.0190
	24	24	24	24	23	24	24	24	24	24	24	24	24
OX3	0.23006	-0.44709	1.00000	0.46854	0.00706	-0.78826	-0.62931	-0.84408	-0.34869	-0.84506	-0.71529	-0.80369	-0.19369
	0.2795	0.0285	0.0000	0.0209	0.9745	0.0001	0.0010	0.0001	0.0949	0.0001	0.0001	0.0001	0.3645
	24	24	24	24	23	24	24	24	24	24	24	24	24
OX2_3	0.66985	0.58075	0.46854	1.00000	0.38700	-0.41361	0.02625	-0.26752	-0.46099	-0.32237	-0.45085	-0.40041	0.29275
	0.0003	0.0029	0.0209	0.0000	0.0681	0.0445	0.9031	0.2063	0.0234	0.1245	0.0270	0.0525	0.1651
	24	24	24	24	23	24	24	24	24	24	24	24	24
NO3N	0.69838	0.37898	0.00706	0.38700	1.00000	-0.02298	0.56698	0.25597	-0.47447	0.16886	-0.14318	0.01074	0.65974
	0.0001	0.0745	0.9745	0.0681	0.0000	0.9132	0.0031	0.2169	0.0166	0.4197	0.4949	0.9594	0.0003
	24	23	23	23	25	25	25	25	25	25	25	25	25
AIR1	-0.12417	0.30759	-0.78826	-0.41361	-0.02298	1.00000	0.54336	0.92222	0.73210	0.96393	0.98526	0.99889	-0.07920
	0.5543	0.1437	0.0001	0.0445	0.9132	0.0000	0.0034	0.0001	0.0001	0.0001	0.0001	0.0001	0.6945
	25	24	24	24	25	27	27	27	27	27	27	27	27
AIR2	0.44259	0.60648	-0.62931	0.02625	0.56698	0.54336	1.00000	0.02571	-0.17407	0.74721	0.39176	0.58239	0.79392
	0.0267	0.0017	0.0010	0.9031	0.0031	0.0034	0.0000	0.0001	0.3852	0.0001	0.0433	0.0014	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
AIR3	0.12806	0.50694	-0.84408	-0.26752	0.25597	0.92222	0.82571	1.00000	0.41176	0.99187	0.84249	0.93944	0.31241
	0.5418	0.0115	0.0001	0.2063	0.2168	0.0001	0.0001	0.0000	0.0328	0.0001	0.0001	0.0001	0.1125
	25	24	24	24	25	27	27	27	27	27	27	27	27
AIR4	-0.48796	-0.14544	-0.34869	-0.46099	-0.47447	0.73210	-0.17407	0.41176	1.00000	0.52439	0.93793	0.69913	-0.73704
	0.0133	0.4977	0.0949	0.0234	0.0166	0.0001	0.3052	0.0328	0.0000	0.0050	0.0001	0.0001	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOL1	0.04715	0.45231	-0.84506	-0.32237	0.16886	0.96393	0.74721	0.99187	0.52438	1.00000	0.90419	0.97542	0.19993
	0.8229	0.0265	0.0001	0.1245	0.4197	0.0001	0.0001	0.0001	0.0050	0.0000	0.0001	0.0001	0.3451
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOL2	-0.22699	0.20264	-0.71529	-0.45085	-0.14318	0.98526	0.39176	0.84249	0.83793	0.90419	1.00000	0.97609	-0.24955
	0.2752	0.3423	0.0001	0.0270	0.4949	0.0001	0.0431	0.0001	0.0001	0.0001	0.0000	0.0001	0.2111
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOL3	-0.09470	0.33517	-0.80369	-0.40041	0.01074	0.99889	0.58239	0.93944	0.69913	0.97542	0.97609	1.00000	-0.03205
	0.6525	0.1094	0.0001	0.0525	0.9594	0.0001	0.0014	0.0001	0.0001	0.0001	0.0001	0.0000	0.8739
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOL4	0.58620	0.47490	-0.19369	0.29276	0.65974	-0.07920	0.79392	0.31241	-0.73704	0.19993	-0.24955	-0.03206	1.00000
	0.0021	0.0190	0.3645	0.1651	0.0001	0.6945	0.0001	0.1126	0.0001	0.3451	0.2111	0.8739	0.0000
	25	24	24	24	25	27	27	27	27	27	27	27	27

	OX	OX2	OX3	OX2_3	NO3N	AIR1	AIR2	AIR3	AIR4	SOL1	SOL2	SOL3	SOL4
SOL5	-0.58873 0.0020 25	-0.44604 0.0289 24	0.13319 0.5350 24	-0.31931 0.1283 24	-0.65355 0.0004 25	0.16218 0.4190 27	-0.74026 0.0001 27	-0.23199 0.2443 27	0.79091 0.0001 27	-0.10631 0.5977 27	0.32957 0.0943 27	0.11542 0.5665 27	-0.99651 0.0001 27
SOL6	-0.58844 0.0020 25	-0.42454 0.0387 24	0.09065 0.6736 24	-0.33680 0.1075 24	-0.64696 0.0005 25	0.21953 0.2712 27	-0.69373 0.0001 27	-0.17478 0.3832 27	0.82530 0.0001 27	-0.04836 0.8119 27	0.38317 0.0485 27	0.17324 0.3875 27	-0.94973 0.0001 27
SOL7	-0.58882 0.0020 25	-0.43956 0.0316 24	0.12017 0.5760 24	-0.32476 0.1215 24	-0.65173 0.0004 25	0.17984 0.3694 27	-0.72809 0.0001 27	-0.21451 0.2826 27	0.80175 0.0001 27	-0.08847 0.6608 27	0.34545 0.0776 27	0.13320 0.5077 27	-0.99485 0.0001 27
SOL8	-0.54083 0.0053 25	-0.56548 0.0040 24	0.42758 0.0371 24	-0.16935 0.4289 24	-0.64478 0.0005 25	-0.25146 0.2058 27	-0.94915 0.0001 27	-0.60614 0.0008 27	0.47522 0.0122 27	-0.50000 0.0079 27	-0.08220 0.6836 27	-0.29687 0.1327 27	-0.94431 0.0001 27
RH1	-0.01602 0.9394 25	-0.42887 0.0365 24	0.84063 0.0001 24	0.34149 0.1024 24	-0.13475 0.5208 25	-0.97570 0.0001 27	-0.71409 0.0001 27	-0.99453 0.0001 27	-0.56506 0.0021 27	-0.99882 0.0001 27	-0.92385 0.0001 27	-0.98496 0.0001 27	-0.14113 0.4825 27
RH2	0.22092 0.2886 25	-0.20922 0.3265 24	0.72046 0.0001 24	0.44906 0.0277 24	0.13597 0.5170 25	-0.98701 0.0001 27	-0.40145 0.0379 27	-0.84813 0.0001 27	-0.83202 0.0001 27	-0.90865 0.0001 27	-0.99994 0.0001 27	-0.97833 0.0001 27	0.23830 0.2313 27
RH3	0.11758 0.5757 25	-0.31385 0.1353 24	0.79192 0.0001 24	0.41075 0.0462 24	0.01541 0.9417 25	-0.99994 0.0001 27	-0.55225 0.0028 27	-0.92628 0.0001 27	-0.72482 0.0001 27	-0.96670 0.0001 27	-0.98339 0.0001 27	-0.99933 0.0001 27	0.06951 0.7339 27
RH4	-0.55285 0.0042 25	-0.27781 0.1887 24	-0.16103 0.4522 24	-0.42093 0.0405 24	-0.57151 0.0029 25	0.53452 0.0041 27	-0.41906 0.0295 27	0.16615 0.4075 27	0.96704 0.0001 27	0.29029 0.1419 27	0.67121 0.0001 27	0.49403 0.0088 27	-0.88484 0.0001 27
RF	0.35254 0.0839 25	-0.05401 0.8021 24	0.58032 0.0030 24	0.47481 0.0190 24	0.29637 0.1503 25	-0.91724 0.0001 27	-0.16399 0.4137 27	-0.69187 0.0001 27	-0.94206 0.0001 27	-0.77813 0.0001 27	-0.97186 0.0001 27	-0.89741 0.0001 27	0.46974 0.0134 27
SR	-0.47982 0.0152 25	-0.13150 0.5402 24	-0.36677 0.0779 24	-0.46367 0.0225 24	-0.46313 0.0197 25	0.74906 0.0001 27	-0.14915 0.4578 27	0.43463 0.0235 27	0.99968 0.0001 27	0.54571 0.0032 27	0.85134 0.0001 27	0.71696 0.0001 27	-0.71975 0.0001 27
WSP	-0.58171 0.0023 25	-0.37281 0.0728 24	-0.00483 0.9821 24	-0.37260 0.0730 24	-0.62559 0.0008 25	0.34450 0.0785 27	-0.60092 0.0009 27	-0.04530 0.8225 27	0.89171 0.0001 27	0.08220 0.6836 27	0.50000 0.0079 27	0.29980 0.1287 27	-0.96312 0.0001 27
AIR1SQ	-0.13488 0.5204 25	0.29730 0.1583 24	-0.78207 0.0001 24	-0.41814 0.0420 24	-0.03531 0.8669 25	0.99985 0.0001 27	0.52874 0.0046 27	0.91538 0.0001 27	0.74379 0.0001 27	0.95917 0.0001 27	0.98909 0.0001 27	0.99792 0.0001 27	-0.09646 0.6322 27
AIR2SQ	0.45117 0.0236 25	0.60541 0.0017 24	-0.61648 0.0014 24	0.03688 0.8642 24	0.57449 0.0027 25	0.52452 0.0050 27	0.99975 0.0001 27	0.81293 0.0001 27	-0.19598 0.3272 27	0.73221 0.0001 27	0.37116 0.0566 27	0.56412 0.0022 27	0.80719 0.0001 27

	OX	OX2	OX3	OX2_3	NO3N	AIR1	AIR2	AIR3	AIR4	SOL1	SOL2	SOL3	SOL4
AIR3SQ	0.13344	0.51023	-0.84335	-0.26361	0.26160	0.91886	0.83053	0.99996	0.40390	0.99074	0.83782	0.93646	0.32059
	0.5249	0.0109	0.0001	0.2133	0.2064	0.0001	0.0001	0.0001	0.0367	0.0001	0.0001	0.0001	0.1033
	25	24	24	24	25	27	27	27	27	27	27	27	27
AIR4SQ	-0.43921	-0.14762	-0.34583	-0.46054	-0.47623	0.72938	-0.17799	0.40813	0.99999	0.52099	0.83565	0.69628	-0.73973
	0.0131	0.4912	0.0979	0.0235	0.0161	0.0001	0.3744	0.0346	0.0001	0.0053	0.0001	0.0001	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOL1SQ	0.04715	0.45231	-0.84506	-0.32237	0.16985	0.96393	0.74721	0.99187	0.52438	1.00000	0.90419	0.97542	0.19993
	0.8229	0.0265	0.0001	0.1245	0.4197	0.0001	0.0001	0.0001	0.0050	0.0001	0.0001	0.0001	0.3451
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOL2SQ	-0.23284	0.19624	-0.71020	-0.45253	-0.15015	0.98346	0.38231	0.83692	0.84339	0.89977	0.99995	0.97381	-0.25845
	0.2627	0.3581	0.0001	0.0264	0.4738	0.0001	0.0491	0.0001	0.0001	0.0001	0.0001	0.0001	0.1933
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOL3SQ	-0.09863	0.33156	-0.80177	-0.40223	0.00626	0.99916	0.57729	0.93728	0.70359	0.97402	0.97741	0.99998	-0.03931
	0.6390	0.1135	0.0001	0.0513	0.9763	0.0001	0.0016	0.0001	0.0001	0.0001	0.0001	0.0001	0.8495
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOL4SQ	0.57820	0.50741	-0.26781	0.25741	0.66198	0.02426	0.85243	0.40893	-0.66324	0.28947	-0.14709	0.07143	0.99464
	0.0025	0.0114	0.2058	0.2246	0.0003	0.9044	0.0001	0.0342	0.0002	0.1430	0.4641	0.7233	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOL5SQ	-0.58882	-0.43941	0.11988	-0.32488	-0.65169	0.18023	-0.72782	-0.21413	0.80199	-0.08808	0.34582	0.13360	-0.99481
	0.0020	0.0317	0.5769	0.1214	0.0004	0.3683	0.0001	0.2835	0.0001	0.6622	0.0772	0.5065	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOL6SQ	-0.58804	-0.41809	0.07824	-0.34172	-0.64469	0.23609	-0.68748	-0.15901	0.83478	-0.03137	0.39982	0.18996	-0.98733
	0.0020	0.0420	0.7163	0.1022	0.0005	0.2358	0.0001	0.4312	0.0001	0.8777	0.0393	0.3426	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOL7SQ	-0.58875	-0.43297	0.10711	-0.33014	-0.64973	0.19745	-0.71568	-0.19696	0.81234	-0.07060	0.36222	0.15095	-0.99287
	0.0020	0.0346	0.6184	0.1151	0.0004	0.3235	0.0001	0.3248	0.0001	0.7264	0.0633	0.4523	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOL8SQ	-0.54083	-0.56548	0.42758	-0.16935	-0.64478	-0.25146	-0.94916	-0.60614	0.47522	-0.50000	-0.08220	-0.29687	-0.94491
	0.0053	0.0040	0.0371	0.4289	0.0005	0.2058	0.0001	0.0008	0.0122	0.0079	0.6836	0.1327	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
RH1SQ	-0.01798	-0.43038	0.84098	0.34032	-0.13690	-0.97503	-0.71622	-0.98506	-0.56255	-0.99897	-0.92269	-0.98443	-0.14414
	0.9320	0.0358	0.0001	0.1037	0.5141	0.0001	0.0001	0.0001	0.0023	0.0001	0.0001	0.0001	0.4732
	25	24	24	24	25	27	27	27	27	27	27	27	27
RH2SQ	0.19688	-0.23481	0.73985	0.44143	0.10755	-0.99280	-0.43888	-0.86925	-0.80844	-0.92510	-0.99866	-0.98604	0.19806
	0.3455	0.2694	0.0001	0.0308	0.6089	0.0001	0.0220	0.0001	0.0001	0.0001	0.0001	0.0001	0.3223
	25	24	24	24	25	27	27	27	27	27	27	27	27
RH3SQ	0.10507	-0.32559	0.79853	0.40518	0.00109	-0.99953	-0.56886	-0.93364	-0.71086	-0.97164	-0.97955	-0.99986	0.04859
	0.6172	0.1205	0.0001	0.0495	0.9959	0.0001	0.0020	0.0001	0.0001	0.0001	0.0001	0.0001	0.8093
	25	24	24	24	25	27	27	27	27	27	27	27	27

	OX	OX2	OX3	OX2_3	NO3N	AIR1	AIR2	AIR3	AIR4	SOL1	SOL2	SOL3	SOL4
RH4SQ	-0.54949	-0.26941	-0.17387	-0.42432	-0.56601	0.54920	-0.40314	0.19335	0.97134	0.30636	0.68405	0.50914	-0.87656
	0.0045	0.2030	0.4165	0.0388	0.0032	0.0030	0.0371	0.3600	0.0001	0.1194	0.0001	0.0067	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
RPSQ	0.23378	-0.19521	0.70937	0.45280	0.15127	-0.98316	-0.38078	-0.83602	-0.84427	-0.89905	-0.99993	-0.97343	0.26005
	0.2607	0.3607	0.0001	0.0263	0.4704	0.0001	0.0501	0.0001	0.0001	0.0001	0.0001	0.0001	0.1902
	25	24	24	24	25	27	27	27	27	27	27	27	27
SRSQ	-0.48490	-0.14014	-0.35559	-0.46204	-0.47017	0.73862	-0.16458	0.42051	0.99995	0.53255	0.84304	0.70598	-0.73053
	0.0140	0.5137	0.0881	0.0230	0.0177	0.0001	0.4120	0.0290	0.0001	0.0043	0.0001	0.0001	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
WSPSQ	-0.57707	-0.35225	-0.04050	-0.39476	-0.61532	0.38962	-0.56145	0.00320	0.91261	0.13043	0.54141	0.34571	-0.94894
	0.0025	0.0914	0.8510	0.0634	0.0011	0.0445	0.0023	0.9874	0.0001	0.5167	0.0036	0.0773	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOLTN	0.54322	0.21247	0.24754	0.43513	0.56678	-0.60038	0.34179	-0.24600	-0.98158	-0.36693	-0.72764	-0.56215	0.84078
	0.0050	0.3189	0.2435	0.0336	0.0032	0.0009	0.0810	0.2161	0.0001	0.0597	0.0001	0.0023	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOLCA	-0.49392	-0.21790	-0.31422	-0.50118	-0.57733	0.65079	-0.22943	0.33162	0.94954	0.44246	0.75999	0.61728	-0.74383
	0.0121	0.3064	0.1348	0.0126	0.0025	0.0002	0.2497	0.0911	0.0001	0.0208	0.0001	0.0006	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOLMG	-0.53858	-0.20071	-0.35244	-0.51899	-0.54420	0.70019	-0.19398	0.38115	0.97872	0.49280	0.80691	0.66711	-0.73757
	0.0055	0.3470	0.0912	0.0094	0.0049	0.0001	0.3323	0.0498	0.0001	0.0090	0.0001	0.0001	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOLK	-0.34541	-0.20800	-0.10329	-0.29944	-0.51043	0.42326	-0.28619	0.15259	0.72872	0.24434	0.52220	0.39377	-0.64645
	0.0908	0.3294	0.6310	0.1552	0.0091	0.0278	0.1478	0.4474	0.0001	0.2193	0.0052	0.0421	0.0003
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOLNA	-0.52915	-0.14967	-0.39355	-0.50599	-0.50246	0.74280	-0.14468	0.43248	0.98870	0.54216	0.84356	0.71114	-0.70999
	0.0065	0.4852	0.0571	0.0116	0.0105	0.0001	0.4715	0.0243	0.0001	0.0035	0.0001	0.0001	0.0001
	25	24	24	24	25	27	27	27	27	27	27	27	27
SOLP	-0.27759	-0.14819	-0.43908	-0.54596	-0.03529	0.42465	0.37129	0.45636	0.19684	0.45389	0.38975	0.43208	0.13326
	0.1791	0.4895	0.0318	0.0058	0.8670	0.0273	0.0565	0.0167	0.3251	0.0174	0.0445	0.0244	0.5075
	25	24	24	24	25	27	27	27	27	27	27	27	27

	SOL5	SOL6	SOL7	SOL8	RH1	RH2	RH3	RH4	RP	SR	WSP	AIR1SQ	AIR2SQ
OX	-0.58873	-0.58844	-0.58982	-0.54083	-0.01602	0.22092	0.11759	-0.55295	0.35254	-0.47992	-0.58171	-0.13488	0.45117
	0.0020	0.0020	0.0020	0.0053	0.9394	0.2886	0.5757	0.0042	0.0839	0.0152	0.0023	0.5204	0.0235
	25	25	25	25	25	25	25	25	25	25	25	25	25
OX2	-0.44604	-0.42454	-0.43956	-0.56548	-0.42987	-0.20922	-0.31385	-0.27781	-0.05401	-0.13150	-0.37281	0.29730	0.60541
	0.0289	0.0387	0.0316	0.0040	0.0365	0.3265	0.1353	0.1887	0.8021	0.5402	0.0723	0.1583	0.0017
	24	24	24	24	24	24	24	24	24	24	24	24	24
OX3	0.13310	0.09065	0.12017	0.42758	0.44063	0.72046	0.79192	-0.16103	0.59032	-0.36677	-0.00481	-0.74207	-0.51648
	0.5350	0.6736	0.5760	0.0371	0.0031	0.0001	0.0001	0.4522	0.0030	0.0779	0.9821	0.0001	0.0014
	24	24	24	24	24	24	24	24	24	24	24	24	24

	SOL5	SOL6	SOL7	SOL8	RH1	RH2	RH3	RH4	RP	SR	WSP	AIR1SQ	AIR2SQ
OX2_3	-0.31931	-0.33680	-0.32476	-0.16935	0.34149	0.44906	0.41075	-0.42093	0.47481	-0.46367	-0.37260	-0.41814	0.01698
	0.1283	0.1075	0.1215	0.4289	0.1024	0.0277	0.0462	0.0405	0.0190	0.0225	0.0730	0.0420	0.8642
	24	24	24	24	24	24	24	24	24	24	24	24	24
NO3N	-0.65355	-0.64696	-0.65173	-0.64478	-0.13475	0.13597	0.01541	-0.57151	0.29637	-0.46313	-0.62559	-0.03531	0.57443
	0.0004	0.0005	0.0004	0.0005	0.5209	0.5170	0.9417	0.0029	0.1503	0.0197	0.0009	0.8669	0.0027
	25	25	25	25	25	25	25	25	25	25	25	25	25
AIR1	0.16219	0.21953	0.17984	-0.25146	-0.97570	-0.98701	-0.99994	0.53452	-0.91724	0.74906	0.34450	0.99985	0.52452
	0.4190	0.2712	0.3694	0.2058	0.0001	0.0001	0.0001	0.0041	0.0001	0.0001	0.0785	0.0001	0.0050
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR2	-0.74026	-0.69973	-0.72809	-0.94916	-0.71409	-0.40146	-0.55225	-0.41906	-0.16399	-0.14915	-0.60092	0.52874	0.99975
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0379	0.0028	0.0296	0.4137	0.4578	0.0009	0.0046	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR3	-0.23198	-0.17478	-0.21451	-0.60614	-0.98453	-0.84813	-0.92628	0.16615	-0.69187	0.43463	-0.04530	0.91538	0.91293
	0.2443	0.3832	0.2826	0.0008	0.0001	0.0001	0.0001	0.4075	0.0001	0.0235	0.8225	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR4	0.79091	0.82530	0.80175	0.47522	-0.56506	-0.83202	-0.72482	0.96704	-0.94286	0.99968	0.89171	0.74379	-0.19598
	0.0001	0.0001	0.0001	0.0122	0.0021	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.3272
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL1	-0.10631	-0.04806	-0.08847	-0.50000	-0.99882	-0.90865	-0.96670	0.29029	-0.77813	0.54571	0.08220	0.95917	0.73221
	0.5977	0.8119	0.6608	0.0079	0.0001	0.0001	0.0001	0.1419	0.0001	0.0032	0.6836	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL2	0.32857	0.38317	0.34545	-0.08220	-0.92385	-0.99994	-0.98339	0.67121	-0.97186	0.85134	0.50000	0.98809	0.37116
	0.0943	0.0485	0.0776	0.6836	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0079	0.0001	0.0555
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL3	0.11542	0.17324	0.13320	-0.29687	-0.98496	-0.97833	-0.99933	0.49403	-0.89741	0.71696	0.29980	0.99792	0.56412
	0.5665	0.3875	0.5077	0.1327	0.0001	0.0001	0.0001	0.0088	0.0001	0.0001	0.1287	0.0001	0.0022
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL4	-0.99651	-0.98993	-0.99485	-0.94491	-0.14113	0.23930	0.06861	-0.88484	0.46974	-0.71975	-0.96312	-0.09646	0.80719
	0.0001	0.0001	0.0001	0.0001	0.4826	0.2313	0.7338	0.0001	0.0134	0.0001	0.0001	0.6322	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL5	1.00000	0.99829	0.99984	0.91427	0.05796	-0.31858	-0.15169	0.92065	-0.54132	0.77521	0.98223	0.17925	-0.75596
	0.0000	0.0001	0.0001	0.0001	0.7740	0.1053	0.4501	0.0001	0.0035	0.0001	0.0001	0.3710	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL6	0.99829	1.00000	0.99918	0.88905	-0.00045	-0.37340	-0.20916	0.94188	-0.58999	0.81078	0.99151	0.23641	-0.71549
	0.0001	0.0000	0.0001	0.0001	0.9982	0.0550	0.2951	0.0001	0.0012	0.0001	0.0001	0.2352	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL7	0.99984	0.99918	1.00000	0.90647	0.04006	-0.33552	-0.16933	0.92750	-0.55680	0.78641	0.98543	0.19686	-0.74317
	0.0001	0.0001	0.0000	0.0001	0.8428	0.0871	0.3981	0.0001	0.0026	0.0001	0.0001	0.3250	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27

	SOL5	SOL6	SOL7	SOL8	RH1	RH2	RH3	RH4	RF	SR	WSP	AIR1SQ	AIR2SQ
SOL8	0.91427	0.88905	0.90687	1.00000	0.45740	0.09272	0.26173	0.68359	-0.15489	0.45285	0.82199	-0.23465	-0.95594
	0.0001	0.0001	0.0001	0.0000	0.0164	0.6455	0.1873	0.0001	0.4404	0.0177	0.0001	0.2387	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
RH1	0.05796	-0.00045	0.04006	0.45740	1.00000	0.92784	0.97798	-0.33637	0.80768	-0.58571	-0.13044	-0.97176	-0.69831
	0.7740	0.9982	0.8428	0.0164	0.0000	0.0001	0.0001	0.0863	0.0001	0.0013	0.5167	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
RH2	-0.31858	-0.37340	-0.33552	0.09272	0.92784	1.00000	0.98525	-0.66334	0.96931	-0.84576	-0.49083	-0.98965	-0.38094
	0.1053	0.0550	0.0871	0.6455	0.0001	0.0000	0.0001	0.0002	0.0001	0.0001	0.0093	0.0001	0.0499
	27	27	27	27	27	27	27	27	27	27	27	27	27
RH3	-0.15169	-0.20916	-0.16938	0.26173	0.97798	0.98525	1.00000	-0.52551	0.91295	-0.74198	-0.33451	-0.99961	-0.53353
	0.4501	0.2951	0.3983	0.1873	0.0001	0.0001	0.0000	0.0049	0.0001	0.0001	0.0881	0.0001	0.0042
	27	27	27	27	27	27	27	27	27	27	27	27	27
RH4	0.92065	0.94188	0.92750	0.68359	-0.33637	-0.66334	-0.52551	1.00000	-0.82694	0.96030	0.97756	0.54909	-0.43920
	0.0001	0.0001	0.0001	0.0001	0.0863	0.0002	0.0049	0.0000	0.0001	0.0001	0.0001	0.0030	0.0219
	27	27	27	27	27	27	27	27	27	27	27	27	27
RF	-0.54182	-0.58999	-0.55680	-0.15489	0.80768	0.96931	0.91295	-0.82694	1.00000	-0.95097	-0.68994	-0.92400	-0.14196
	0.0035	0.0012	0.0026	0.4404	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.4800
	27	27	27	27	27	27	27	27	27	27	27	27	27
SR	0.77521	0.91078	0.78641	0.45285	-0.58571	-0.84576	-0.74198	0.96030	-0.95097	1.00000	0.88000	0.76043	-0.17116
	0.0001	0.0001	0.0001	0.0177	0.0013	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.3933
	27	27	27	27	27	27	27	27	27	27	27	27	27
WSP	0.98223	0.99151	0.98543	0.82199	-0.13044	-0.49083	-0.33451	0.97756	-0.68994	0.88000	1.00000	0.36071	-0.61859
	0.0001	0.0001	0.0001	0.0001	0.5167	0.0093	0.0881	0.0001	0.0001	0.0001	0.0000	0.0645	0.0006
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR1SQ	0.17925	0.23641	0.19686	-0.23465	-0.97176	-0.98965	-0.99961	0.54909	-0.92400	0.76043	0.36071	1.00000	0.50969
	0.3710	0.2352	0.3250	0.2387	0.0001	0.0001	0.0001	0.0030	0.0001	0.0001	0.0645	0.0000	0.0065
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR2SQ	-0.75506	-0.71548	-0.74319	-0.95594	-0.69831	-0.38094	-0.53353	-0.43920	-0.14196	-0.17116	-0.61859	0.50969	1.00000
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0499	0.0042	0.0219	0.4800	0.3933	0.0006	0.0066	0.0000
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR3SQ	-0.24035	-0.18325	-0.22292	-0.61297	-0.98298	-0.84354	-0.92300	0.15766	-0.68563	0.42686	-0.05390	0.91188	0.81791
	0.2272	0.3602	0.2637	0.0007	0.0001	0.0001	0.0001	0.4322	0.0001	0.0264	0.7895	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR4SQ	0.79334	0.82754	0.80412	0.47871	-0.56178	-0.82980	-0.72207	0.96805	-0.94152	0.99957	0.89350	0.74113	-0.19937
	0.0001	0.0001	0.0001	0.0115	0.0023	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.3175
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL1SQ	-0.10631	-0.04806	-0.08847	-0.50000	-0.99882	-0.90865	-0.96670	0.29029	-0.77813	0.54571	0.08220	0.95917	0.73221
	0.5977	0.8119	0.6608	0.0079	0.0001	0.0001	0.0001	0.1419	0.0001	0.0032	0.6836	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27

	SOL5	SOL6	SOL7	SOL8	RH1	RH2	RH3	RH4	RF	SB	WSP	AIR1SQ	AIR2SQ
SOL2SQ	0.33824	0.39262	0.35505	-0.07198	-0.91989	-0.99974	-0.98149	0.67877	-0.97422	0.85668	0.50885	0.98645	0.35152
	0.0844	0.0428	0.0692	0.7212	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0067	0.0001	0.0639
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL3SQ	0.12163	0.17940	0.13940	-0.29088	-0.93386	-0.97961	-0.99954	0.49946	-0.90016	0.72130	0.30576	0.99830	0.55834
	0.5456	0.3706	0.4880	0.1410	0.0001	0.0001	0.0001	0.0090	0.0001	0.0001	0.1209	0.0001	0.0025
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL4SQ	-0.98254	-0.96999	-0.97904	-0.97368	-0.24270	0.13664	-0.03488	-0.83194	0.37597	-0.64413	-0.93015	0.00594	0.86333
	0.0001	0.0001	0.0001	0.0001	0.2225	0.4968	0.8629	0.0001	0.0533	0.0003	0.0001	0.9726	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL5SQ	0.99983	0.99920	1.00000	0.90670	0.03966	-0.33589	-0.16977	0.92765	-0.55713	0.78665	0.98550	0.19724	-0.74233
	0.0001	0.0001	0.0001	0.0001	0.8443	0.0867	0.3972	0.0001	0.0026	0.0001	0.0001	0.3241	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL6SQ	0.99716	0.99986	0.99835	0.88114	-0.01745	-0.38912	-0.22575	0.94746	-0.60363	0.82062	0.99358	0.25289	-0.70350
	0.0001	0.0001	0.0001	0.0001	0.9312	0.0448	0.2575	0.0001	0.0009	0.0001	0.0001	0.2031	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL7SQ	0.99936	0.99975	0.99984	0.89916	0.02213	-0.35236	-0.18702	0.93406	-0.57161	0.79736	0.98833	0.21441	-0.73107
	0.0001	0.0001	0.0001	0.0001	0.9128	0.0715	0.3503	0.0001	0.0019	0.0001	0.0001	0.2829	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL8SQ	0.91427	0.88905	0.90687	1.00000	0.45740	0.09272	0.26173	0.68359	-0.15489	0.45295	0.82199	-0.23465	-0.95534
	0.0001	0.0001	0.0001	0.0001	0.0164	0.6455	0.1873	0.0001	0.4404	0.0177	0.0001	0.2387	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
RH1SQ	0.06099	0.00259	0.04310	0.46011	1.00000	0.92670	0.97734	-0.33350	0.80588	-0.58324	-0.12743	-0.97104	-0.70049
	0.7625	0.9898	0.8310	0.0157	0.0001	0.0001	0.0001	0.0891	0.0001	0.0014	0.5265	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
RH2SQ	-0.27923	-0.33483	-0.29639	0.13369	0.94243	0.99915	0.99147	-0.63192	0.95835	-0.82304	-0.45449	-0.99472	-0.41974
	0.1584	0.0878	0.1333	0.5062	0.0001	0.0001	0.0001	0.0004	0.0001	0.0001	0.0172	0.0001	0.0297
	27	27	27	27	27	27	27	27	27	27	27	27	27
RH3SQ	-0.13184	-0.19951	-0.14958	0.28103	0.98196	0.98162	0.99980	-0.50935	0.90459	-0.72839	-0.31554	-0.99885	-0.55038
	0.5121	0.3438	0.4565	0.1556	0.0001	0.0001	0.0001	0.0068	0.0001	0.0001	0.1089	0.0001	0.0029
	27	27	27	27	27	27	27	27	27	27	27	27	27
RH4SQ	0.91370	0.93587	0.92083	0.67074	-0.35276	-0.67631	-0.54029	0.99985	-0.83664	0.96503	0.97373	0.56360	-0.42349
	0.0001	0.0001	0.0001	0.0001	0.0711	0.0001	0.0036	0.0001	0.0001	0.0001	0.0001	0.0022	0.0277
	27	27	27	27	27	27	27	27	27	27	27	27	27
RFSQ	-0.33980	-0.39414	-0.35660	0.07033	0.91923	0.99975	0.98116	-0.67999	0.97459	-0.85753	-0.51028	-0.98618	-0.36007
	0.0829	0.0419	0.0679	0.7274	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0065	0.0001	0.0651
	27	27	27	27	27	27	27	27	27	27	27	27	27
SBSQ	0.79499	0.81983	0.79596	0.46673	-0.57298	-0.83732	-0.73142	0.96455	-0.94602	0.99988	0.88731	0.75019	-0.18653
	0.0001	0.0001	0.0001	0.0141	0.0018	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.3516
	27	27	27	27	27	27	27	27	27	27	27	27	27

	SOL5	SOL6	SOL7	SOL8	RH1	RH2	RH3	RH4	RF	SR	WSP	AIR1SQ	AIR2SQ
WSPSQ	0.97197	0.98404	0.97603	0.79341	-0.17837	-0.53250	-0.37991	0.98663	-0.72423	0.90139	0.99882	0.40552	-0.57976
	0.0001	0.0001	0.0001	0.0001	0.3734	0.0043	0.0507	0.0001	0.0001	0.0001	0.0001	0.0359	0.0015
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOLIN	-0.98256	-0.90812	-0.89072	-0.61919	0.41145	0.72040	0.59189	-0.99343	0.86766	-0.97639	-0.95385	-0.61407	0.36257
	0.0001	0.0001	0.0001	0.0006	0.0330	0.0001	0.0012	0.0001	0.0001	0.0001	0.0001	0.0007	0.0631
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOLCA	0.79087	0.82044	0.80023	0.50855	-0.48281	-0.75390	-0.64337	0.93483	-0.97358	0.94760	0.87620	0.66273	-0.24995
	0.0001	0.0001	0.0001	0.0068	0.0107	0.0001	0.0003	0.0001	0.0001	0.0001	0.0001	0.0002	0.2086
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOLMG	0.78876	0.92128	0.79902	0.48620	-0.53326	-0.80101	-0.69288	0.95257	-0.91481	0.97730	0.88359	0.71194	-0.21532
	0.0001	0.0001	0.0001	0.0101	0.0042	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.2803
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOLK	0.67537	0.69279	0.68096	0.48868	-0.27826	-0.51654	-0.41671	0.74590	-0.63316	0.72440	0.72304	0.43385	-0.30149
	0.0001	0.0001	0.0001	0.0097	0.1599	0.0058	0.0306	0.0001	0.0004	0.0001	0.0001	0.0238	0.1264
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOLNA	0.76494	0.90025	0.77605	0.44535	-0.58165	-0.83806	-0.73582	0.94903	-0.94148	0.98909	0.86903	0.75400	-0.16646
	0.0001	0.0001	0.0001	0.0199	0.0015	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.4066
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOLP	-0.09634	-0.07011	-0.08832	-0.26882	-0.45101	-0.39224	-0.42649	0.08549	-0.32281	0.20717	-0.01080	0.42168	0.36528
	0.6327	0.7282	0.6613	0.1751	0.0182	0.0430	0.0266	0.6716	0.1005	0.2998	0.9570	0.0285	0.0610
	27	27	27	27	27	27	27	27	27	27	27	27	27

	AIR3SQ	AIR4SQ	SOL1SQ	SOL2SQ	SOL3SQ	SOL4SQ	SOL5SQ	SOL6SQ	SOL7SQ	SOL8SQ	RH1SQ	RH2SQ	RH3SQ
OX	0.13344	-0.49921	0.04715	-0.23284	-0.09863	0.57820	-0.58882	-0.58304	-0.58875	-0.54083	-0.01798	0.19688	0.10507
	0.5249	0.0131	0.8229	0.2627	0.6390	0.0025	0.0020	0.0020	0.0020	0.0053	0.9320	0.3455	0.6172
	25	25	25	25	25	25	25	25	25	25	25	25	25
OX2	0.51023	-0.14762	0.45231	0.19624	0.33156	0.50741	-0.43941	-0.41809	-0.43297	-0.56548	-0.43038	-0.23491	-0.32559
	0.0109	0.4912	0.0265	0.3581	0.1135	0.0114	0.0317	0.0420	0.0346	0.0040	0.0358	0.2694	0.1205
	24	24	24	24	24	24	24	24	24	24	24	24	24
OX3	-0.84335	-0.34583	-0.84506	-0.71020	-0.80177	-0.26781	0.11988	0.07824	0.10711	0.42758	0.84098	0.73985	0.79853
	0.0001	0.0979	0.0001	0.0001	0.0001	0.2058	0.5769	0.7163	0.6184	0.0371	0.0001	0.0001	0.0001
	24	24	24	24	24	24	24	24	24	24	24	24	24
OX2_3	-0.26361	-0.46054	-0.32237	-0.45253	-0.40223	0.25741	-0.32488	-0.34172	-0.33014	-0.16935	0.34032	0.44143	0.40519
	0.2133	0.0235	0.1245	0.0264	0.0513	0.2246	0.1214	0.1022	0.1151	0.4289	0.1037	0.0308	0.0495
	24	24	24	24	24	24	24	24	24	24	24	24	24
NO3N	0.26168	-0.47623	0.16886	-0.15015	0.00626	0.66198	-0.65169	-0.64469	-0.64973	-0.64478	-0.13690	0.10755	0.00133
	0.2064	0.0161	0.4197	0.4738	0.9763	0.0003	0.0004	0.0005	0.0004	0.0005	0.5141	0.6089	0.9953
	25	25	25	25	25	25	25	25	25	25	25	25	25
AIR1	0.91886	0.72938	0.96393	0.98346	0.99916	0.02426	0.18023	0.23609	0.19745	-0.25146	-0.97503	-0.99280	-0.99953
	0.0001	0.0001	0.0001	0.0001	0.0001	0.9044	0.3683	0.2358	0.3235	0.2058	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27

	AIR3SQ	AIR4SQ	SOL1SQ	SOL2SQ	SOL3SQ	SOL4SQ	SOL5SQ	SOL6SQ	SOL7SQ	SOL8SQ	RH1SQ	RH2SQ	RH3SQ
AIR2	0.93053	-0.17798	0.74721	0.38231	0.57729	0.85243	-0.72782	-0.68748	-0.71568	-0.94916	-0.71622	-0.43883	-0.56895
	0.0001	0.3744	0.0001	0.0491	0.0016	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0220	0.0020
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR3	0.99996	0.40813	0.99187	0.83692	0.93728	0.40893	-0.21413	-0.15801	-0.19696	-0.60614	-0.98505	-0.86925	-0.93364
	0.0001	0.0346	0.0001	0.0001	0.0001	0.0342	0.2835	0.4312	0.3249	0.0008	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR4	0.40390	0.99999	0.52438	0.84338	0.70359	-0.66324	0.80199	0.83478	0.81234	0.47522	-0.56255	-0.90944	-0.71095
	0.0367	0.0001	0.0050	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0122	0.0023	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL1	0.99074	0.52099	1.00000	0.89977	0.97402	0.28947	-0.09808	-0.03107	-0.07060	-0.50000	-0.99897	-0.92510	-0.97164
	0.0001	0.0053	0.0001	0.0001	0.0001	0.1430	0.6622	0.8777	0.7264	0.0079	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL2	0.83782	0.83565	0.90419	0.99995	0.97743	-0.14709	0.34582	0.39882	0.36222	-0.08220	-0.92268	-0.99866	-0.97955
	0.0001	0.0001	0.0001	0.0001	0.0001	0.4641	0.0772	0.0393	0.0633	0.6836	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL3	0.93646	0.69628	0.97542	0.97381	0.99998	0.07143	0.13360	0.18996	0.15095	-0.29687	-0.98443	-0.98604	-0.99986
	0.0001	0.0001	0.0001	0.0001	0.0001	0.7233	0.5065	0.3426	0.4523	0.1327	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL4	0.32058	-0.73973	0.18998	-0.25846	-0.03831	0.99464	-0.99481	-0.98738	-0.99287	-0.94491	-0.14414	0.19806	0.04859
	0.1030	0.0001	0.3451	0.1930	0.8495	0.0001	0.0001	0.0001	0.0001	0.0001	0.4732	0.3220	0.8093
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL5	-0.24035	0.79334	-0.10631	0.33824	0.12163	-0.98254	0.99983	0.99716	0.99936	0.91427	0.06099	-0.27923	-0.13184
	0.2272	0.0001	0.5977	0.0844	0.5456	0.0001	0.0001	0.0001	0.0001	0.0001	0.7625	0.1584	0.5121
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL6	-0.18325	0.82754	-0.04806	0.39262	0.17940	-0.96999	0.99920	0.99986	0.99975	0.88905	0.00259	-0.33483	-0.19951
	0.3602	0.0001	0.8119	0.0428	0.3706	0.0001	0.0001	0.0001	0.0001	0.0001	0.9898	0.0878	0.3439
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL7	-0.22292	0.80412	-0.08847	0.35505	0.13940	-0.97904	1.00000	0.99835	0.99984	0.90687	0.04310	-0.29639	-0.14953
	0.2637	0.0001	0.6608	0.0692	0.4880	0.0001	0.0001	0.0001	0.0001	0.0001	0.8310	0.1333	0.4565
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL8	-0.61297	0.47871	-0.50000	-0.07198	-0.29088	-0.97369	0.90670	0.88114	0.89916	1.00000	0.46011	0.13369	0.29193
	0.0007	0.0115	0.0079	0.7212	0.1410	0.0001	0.0001	0.0001	0.0001	0.0001	0.0157	0.5062	0.1535
	27	27	27	27	27	27	27	27	27	27	27	27	27
RH1	-0.98298	-0.56178	-0.99882	-0.91988	-0.98386	-0.24270	0.03966	-0.01745	0.02213	0.45740	1.00000	0.94243	0.98195
	0.0001	0.0023	0.0001	0.0001	0.0001	0.2225	0.8443	0.9312	0.9128	0.0164	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
RH2	-0.84354	-0.82980	-0.90865	-0.99978	-0.97961	0.13664	-0.33589	-0.38912	-0.35236	0.09272	0.92670	0.99915	0.99162
	0.0001	0.0001	0.0001	0.0001	0.0001	0.4968	0.0867	0.0448	0.0715	0.6455	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27

	AIR3SQ	AIR4SQ	SOL1SQ	SOL2SQ	SOL3SQ	SOL4SQ	SOL5SQ	SOL6SQ	SOL7SQ	SOL8SQ	RH1SQ	RH2SQ	RH3SQ
RH3	-0.92300	-0.72207	-0.96670	-0.98148	-0.99954	-0.03489	-0.16977	-0.22575	-0.18702	0.26173	0.97734	0.99147	0.99931
	0.0001	0.0001	0.0001	0.0001	0.0001	0.8629	0.3972	0.2575	0.3503	0.1873	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
RH4	0.15766	0.96805	0.29029	0.67877	0.49946	-0.83194	0.92765	0.94746	0.93406	0.68359	-0.33150	-0.63192	-0.59835
	0.4322	0.0001	0.1419	0.0001	0.0080	0.0001	0.0001	0.0001	0.0001	0.0001	0.0491	0.0004	0.0063
	27	27	27	27	27	27	27	27	27	27	27	27	27
EF	-0.68563	-0.94152	-0.77813	-0.97422	-0.90016	0.37597	-0.55713	-0.60363	-0.57161	-0.15489	0.80589	0.95835	0.93459
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0533	0.0026	0.0009	0.0019	0.4434	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SR	0.42686	0.93957	0.54571	0.85668	0.72130	-0.64413	0.78665	0.82062	0.79736	0.45285	-0.58324	-0.82304	-0.72839
	0.0264	0.0001	0.0032	0.0001	0.0001	0.0003	0.0001	0.0001	0.0001	0.0177	0.0014	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
WSP	-0.05390	0.89350	0.08220	0.50885	0.30576	-0.93015	0.98550	0.99358	0.98833	0.82199	-0.12743	-0.45449	-0.31554
	0.7895	0.0001	0.6836	0.0067	0.1209	0.0001	0.0001	0.0001	0.0001	0.0001	0.5265	0.0172	0.1089
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR1SQ	0.91188	0.74113	0.95917	0.98645	0.99830	0.00694	0.19724	0.25289	0.21441	-0.23465	-0.97104	-0.99472	-0.99885
	0.0001	0.0001	0.0001	0.0001	0.0001	0.9726	0.3241	0.2031	0.2829	0.2387	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR2SQ	0.81791	-0.19987	0.73221	0.36162	0.55894	0.86388	-0.74293	-0.70350	-0.73107	-0.95594	-0.70049	-0.41874	-0.55039
	0.0001	0.3175	0.0001	0.0638	0.0025	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0297	0.0029
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR3SQ	1.00000	0.40025	0.99074	0.83218	0.93424	0.41677	-0.22253	-0.16651	-0.20540	-0.61297	-0.98354	-0.86496	-0.93053
	0.0000	0.0386	0.0001	0.0001	0.0001	0.0306	0.2646	0.4065	0.3040	0.0007	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
AIR4SQ	0.40025	1.00000	0.52099	0.84123	0.70076	-0.66621	0.80436	0.83697	0.81465	0.47871	-0.55926	-0.80609	-0.70806
	0.0386	0.0000	0.0053	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0115	0.0024	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL1SQ	0.99074	0.52099	1.00000	0.89977	0.97402	0.28947	-0.08808	-0.03107	-0.07060	-0.50000	-0.99897	-0.92510	-0.97164
	0.0001	0.0053	0.0000	0.0001	0.0001	0.1430	0.6622	0.8777	0.7264	0.0079	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL2SQ	0.83218	0.84123	0.89977	1.00000	0.97521	-0.15722	0.35542	0.40820	0.37175	-0.07198	-0.91868	-0.99808	-0.97744
	0.0001	0.0001	0.0001	0.0000	0.0001	0.4335	0.0689	0.0345	0.0562	0.7212	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL3SQ	0.93424	0.70076	0.97402	0.97521	1.00000	0.06518	0.13980	0.19610	0.15714	-0.29088	-0.98331	-0.98706	-0.99935
	0.0001	0.0001	0.0001	0.0001	0.0000	0.7467	0.4868	0.3269	0.4338	0.1410	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL4SQ	0.41677	-0.66621	0.28947	-0.15722	0.06518	1.00000	-0.97896	-0.96572	-0.97523	-0.97368	-0.24565	0.09568	-0.05491
	0.0306	0.0001	0.1430	0.4335	0.7467	0.0000	0.0001	0.0001	0.0001	0.0001	0.2168	0.6350	0.7856
	27	27	27	27	27	27	27	27	27	27	27	27	27

	AIR3SQ	AIR4SQ	SOL1SQ	SOL2SQ	SOL3SQ	SOL4SQ	SOL5SQ	SOL6SQ	SOL7SQ	SOL8SQ	BB1SQ	BB2SQ	BB3SQ
SOL5SQ	-0.22253	0.80436	-0.08808	0.35542	0.13980	-0.97896	1.00000	0.99837	0.99985	0.90670	0.04270	-0.29677	-0.14998
	0.2646	0.0001	0.6622	0.0689	0.4869	0.0001	0.0000	0.0001	0.0001	0.0001	0.8325	0.1328	0.4553
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL6SQ	-0.16651	0.83697	-0.03107	0.40820	0.19610	-0.96572	0.99837	1.00000	0.99922	0.88114	-0.01441	-0.35081	-0.20617
	0.4065	0.0001	0.8777	0.0345	0.3269	0.0001	0.0001	0.0000	0.0001	0.0001	0.9431	0.0728	0.3022
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL7SQ	-0.20540	0.81465	-0.07060	0.37175	0.15714	-0.97523	0.99985	0.99922	1.00000	0.89916	0.02517	-0.31347	-0.16729
	0.3040	0.0001	0.7264	0.0562	0.4338	0.0001	0.0001	0.0001	0.0000	0.0001	0.9008	0.1113	0.4043
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOL8SQ	-0.61297	0.47871	-0.50000	-0.07198	-0.29088	-0.97368	0.90670	0.88114	0.89916	1.00000	0.46011	0.13369	0.28103
	0.0007	0.0115	0.0079	0.7212	0.1410	0.0001	0.0001	0.0001	0.0001	0.0000	0.0157	0.5062	0.1556
	27	27	27	27	27	27	27	27	27	27	27	27	27
BB1SQ	-0.98354	-0.55926	-0.99897	-0.91868	-0.98331	-0.24565	0.04270	-0.01441	0.02517	0.46011	1.00000	0.94141	0.98138
	0.0001	0.0024	0.0001	0.0001	0.0001	0.2168	0.8325	0.9431	0.9008	0.0157	0.0000	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
BB2SQ	-0.86496	-0.90609	-0.92510	-0.99808	-0.98705	0.09568	-0.29677	-0.35081	-0.31347	0.13369	0.94141	1.00000	0.98866
	0.0001	0.0001	0.0001	0.0001	0.0001	0.6350	0.1328	0.0728	0.1113	0.5062	0.0001	0.0000	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
BB3SQ	-0.93053	-0.70806	-0.97164	-0.97744	-0.99995	-0.05491	-0.14998	-0.20617	-0.16729	0.28103	0.98138	0.98866	1.00000
	0.0001	0.0001	0.0001	0.0001	0.0001	0.7856	0.4553	0.3022	0.4043	0.1556	0.0001	0.0001	0.0000
	27	27	27	27	27	27	27	27	27	27	27	27	27
BB4SQ	0.17488	0.97228	0.30696	0.69149	0.51452	-0.82212	0.92099	0.94173	0.92768	0.67074	-0.34991	-0.64536	-0.52331
	0.3830	0.0001	0.1194	0.0001	0.0060	0.0001	0.0001	0.0001	0.0001	0.0001	0.0736	0.0003	0.0051
	27	27	27	27	27	27	27	27	27	27	27	27	27
BFSQ	-0.83126	-0.84213	-0.89905	-1.00000	-0.97485	0.15886	-0.35697	-0.40971	-0.37329	0.07033	0.91802	0.99797	0.97709
	0.0001	0.0001	0.0001	0.0001	0.0001	0.4287	0.0676	0.0338	0.0551	0.7274	0.0001	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SBSQ	0.41268	0.99991	0.53255	0.84851	0.71039	-0.65600	0.79620	0.82944	0.80669	0.46673	-0.57048	-0.81406	-0.71760
	0.0324	0.0001	0.0043	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0141	0.0019	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
WSPSQ	-0.00541	0.91423	0.13043	0.55000	0.35158	-0.91125	0.97612	0.98693	0.97978	0.79341	-0.17538	-0.49715	-0.36119
	0.9786	0.0001	0.5167	0.0030	0.0721	0.0001	0.0001	0.0001	0.0001	0.0001	0.3816	0.0083	0.0642
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOLTN	-0.23767	-0.98227	-0.36693	-0.73458	-0.56729	0.78093	-0.89090	-0.91497	-0.89860	-0.61919	0.40869	0.69138	0.57569
	0.2326	0.0001	0.0597	0.0001	0.0020	0.0001	0.0001	0.0001	0.0001	0.0006	0.0343	0.0001	0.0017
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOLCA	0.32393	0.94980	0.44246	0.76583	0.62180	-0.67852	0.80043	0.82853	0.80934	0.50855	-0.48031	-0.72931	-0.62918
	0.0993	0.0001	0.0208	0.0001	0.0005	0.0001	0.0001	0.0001	0.0001	0.0068	0.0112	0.0001	0.0004
	27	27	27	27	27	27	27	27	27	27	27	27	27

	AIR3SQ	AIR4SQ	SOL1SQ	SOL2SQ	SOL3SQ	SOL4SQ	SOL5SQ	SOL6SQ	SOL7SQ	SOL8SQ	RH1SQ	RH2SQ	RH3SQ
SOLMG	0.37337	0.97801	0.49280	0.81255	0.67158	-0.66707	0.79925	0.83022	0.80904	0.48620	-0.53076	-0.77712	-0.67887
	0.0551	0.0001	0.0090	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0101	0.0044	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOLK	0.14629	0.72936	0.24434	0.52764	0.39773	-0.60442	0.68108	0.69741	0.68634	0.48869	-0.27616	-0.49388	-0.40421
	0.4665	0.0001	0.2193	0.0047	0.0399	0.0009	0.0001	0.0001	0.0001	0.0097	0.1632	0.0088	0.0365
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOLNA	0.42481	0.98858	0.54216	0.84881	0.71543	-0.63490	0.77630	0.81002	0.78692	0.44535	-0.57922	-0.81569	-0.72242
	0.0272	0.0001	0.0035	0.0001	0.0001	0.0004	0.0001	0.0001	0.0001	0.0199	0.0016	0.0001	0.0001
	27	27	27	27	27	27	27	27	27	27	27	27	27
SOLP	0.45625	0.19520	0.45389	0.38730	0.43115	0.17769	-0.08815	-0.06243	-0.08028	-0.26882	-0.45122	-0.40153	-0.42959
	0.0168	0.3292	0.0174	0.0459	0.0247	0.3753	0.6620	0.7570	0.6906	0.1751	0.0182	0.0379	0.0253
	27	27	27	27	27	27	27	27	27	27	27	27	27

	RH4SQ	RFSQ	SRSQ	WSPSQ	SOLTN	SOLCA	SOLMG	SOLK	SOLNA	SOLP
OX	-0.54949	0.23378	-0.48490	-0.57707	0.54322	-0.49392	-0.53858	-0.34541	-0.52915	-0.27759
	0.0045	0.2607	0.0140	0.0025	0.0050	0.0121	0.0055	0.0908	0.0065	0.1791
	25	25	25	25	25	25	25	25	25	25
OX2	-0.26941	-0.19521	-0.14014	-0.35225	0.21247	-0.21790	-0.20071	-0.20800	-0.14967	-0.14819
	0.2030	0.3607	0.5137	0.0914	0.3189	0.3064	0.3470	0.3294	0.4852	0.4895
	24	24	24	24	24	24	24	24	24	24
OX3	-0.17387	0.70937	-0.35559	-0.04050	0.24754	-0.31422	-0.35244	-0.10329	-0.39355	-0.43908
	0.4165	0.0001	0.0881	0.8510	0.2435	0.1348	0.0912	0.6310	0.0571	0.0318
	24	24	24	24	24	24	24	24	24	24
OX2_3	-0.42432	0.45280	-0.46204	-0.38476	0.43513	-0.50118	-0.51899	-0.29944	-0.50599	-0.54596
	0.0388	0.0263	0.0230	0.0634	0.0336	0.0126	0.0094	0.1552	0.0116	0.0058
	24	24	24	24	24	24	24	24	24	24
NO3N	-0.56601	0.15127	-0.47019	-0.61532	0.56678	-0.57733	-0.54420	-0.51043	-0.50246	-0.03528
	0.0032	0.4704	0.0177	0.0011	0.0032	0.0025	0.0049	0.0091	0.0105	0.8670
	25	25	25	25	25	25	25	25	25	25
AIR1	0.54920	-0.98316	0.73862	0.38962	-0.60038	0.65079	0.70019	0.42326	0.74280	0.42465
	0.0030	0.0001	0.0001	0.0445	0.0009	0.0002	0.0001	0.0278	0.0001	0.0273
	27	27	27	27	27	27	27	27	27	27
AIR2	-0.40314	-0.38078	-0.16458	-0.56145	0.34179	-0.22943	-0.19398	-0.28619	-0.14468	0.37129
	0.0371	0.0501	0.4120	0.0023	0.0810	0.2497	0.3323	0.1478	0.4715	0.0565
	27	27	27	27	27	27	27	27	27	27
AIR3	0.18335	-0.83602	0.42051	0.00320	-0.24600	0.33162	0.38115	0.15259	0.43248	0.45636
	0.3600	0.0001	0.0290	0.9874	0.2161	0.0911	0.0498	0.4474	0.0243	0.0167
	27	27	27	27	27	27	27	27	27	27
AIR4	0.97134	-0.84427	0.99995	0.91261	-0.98158	0.94954	0.97872	0.72872	0.98870	0.19684
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.3251
	27	27	27	27	27	27	27	27	27	27

	RH4SQ	PPSO	SPSO	WSPSO	SOLTN	SOLCA	SOLMG	SOLK	SOLNA	SOLP
SOL1	0.30696	-0.89905	0.53255	0.13043	-0.36693	0.44246	0.49280	0.24434	0.54216	0.45399
	0.1194	0.0001	0.0043	0.5167	0.0597	0.0208	0.0090	0.2193	0.0035	0.0174
	27	27	27	27	27	27	27	27	27	27
SOL2	0.68405	-0.99993	0.84304	0.54141	-0.72764	0.75999	0.80691	0.52220	0.84356	0.38975
	0.0001	0.0001	0.0001	0.0036	0.0001	0.0001	0.0001	0.0052	0.0001	0.0445
	27	27	27	27	27	27	27	27	27	27
SOL3	0.50914	-0.97343	0.70598	0.34571	-0.56215	0.61729	0.66711	0.39377	0.71114	0.43208
	0.0067	0.0001	0.0001	0.0773	0.0021	0.0006	0.0001	0.0421	0.0001	0.0244
	27	27	27	27	27	27	27	27	27	27
SOL4	-0.87656	0.26006	-0.73050	-0.94394	0.84079	-0.74388	-0.73757	-0.64646	-0.70990	0.13326
	0.0001	0.1902	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001	0.5076
	27	27	27	27	27	27	27	27	27	27
SOL5	0.91370	-0.33980	0.78499	0.97197	-0.98256	0.79087	0.78876	0.67537	0.76494	-0.09634
	0.0001	0.0829	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.6327
	27	27	27	27	27	27	27	27	27	27
SOL6	0.93587	-0.39414	0.81983	0.98404	-0.90812	0.82044	0.82128	0.69279	0.80025	-0.07011
	0.0001	0.0419	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.7282
	27	27	27	27	27	27	27	27	27	27
SOL7	0.92083	-0.35660	0.79596	0.97603	-0.89072	0.80023	0.79902	0.68096	0.77605	-0.08832
	0.0001	0.0679	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.6613
	27	27	27	27	27	27	27	27	27	27
SOL8	0.67074	0.07033	0.46673	0.79341	-0.61919	0.50855	0.48620	0.48869	0.44535	-0.26882
	0.0001	0.7274	0.0141	0.0001	0.0006	0.0068	0.0101	0.0097	0.0199	0.1751
	27	27	27	27	27	27	27	27	27	27
RH1	-0.35276	0.91923	-0.57298	-0.17837	0.41145	-0.48281	-0.53326	-0.27826	-0.58165	-0.45101
	0.0711	0.0001	0.0018	0.3734	0.0330	0.0107	0.0042	0.1599	0.0015	0.0182
	27	27	27	27	27	27	27	27	27	27
RH2	-0.67631	0.99975	-0.83732	-0.53250	0.72040	-0.75390	-0.80101	-0.51654	-0.83806	-0.39224
	0.0001	0.0001	0.0001	0.0043	0.0001	0.0001	0.0001	0.0058	0.0001	0.0430
	27	27	27	27	27	27	27	27	27	27
RH3	-0.54029	0.98116	-0.73142	-0.37981	0.59189	-0.64337	-0.69289	-0.41671	-0.73582	-0.42640
	0.0036	0.0001	0.0001	0.0507	0.0012	0.0003	0.0001	0.0306	0.0001	0.0266
	27	27	27	27	27	27	27	27	27	27
RH4	0.99985	-0.67999	0.96455	0.98663	-0.99343	0.93483	0.95257	0.74590	0.94303	0.08549
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.6716
	27	27	27	27	27	27	27	27	27	27
RP	-0.83664	0.97459	-0.94602	-0.72423	0.86766	-0.87358	-0.91481	-0.63316	-0.94148	-0.32281
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0004	0.0001	0.1005
	27	27	27	27	27	27	27	27	27	27

	RHSQ	RPSQ	SRSQ	WSPSQ	SOLTN	SOLCA	SOLMG	SOLK	SOLNA	SOLP
SB	0.96503	-0.85753	0.99988	0.90199	-0.97689	0.94760	0.97780	0.72440	0.98909	0.20717
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.2998
	27	27	27	27	27	27	27	27	27	27
WSP	0.97373	-0.51029	0.88731	0.99882	-0.95385	0.87620	0.88359	0.72304	0.86903	-0.01098
	0.0001	0.0065	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.9570
	27	27	27	27	27	27	27	27	27	27
AIR1SQ	0.56360	-0.98618	0.75019	0.40552	-0.61407	0.66273	0.71194	0.43385	0.75400	0.42168
	0.0022	0.0001	0.0001	0.0359	0.0007	0.0002	0.0001	0.0238	0.0001	0.0285
	27	27	27	27	27	27	27	27	27	27
AIR2SQ	-0.42344	-0.36007	-0.18653	-0.57976	0.36257	-0.24996	-0.21532	-0.30149	-0.16646	0.36528
	0.0277	0.0651	0.3516	0.0015	0.0631	0.2086	0.2808	0.1264	0.4066	0.0610
	27	27	27	27	27	27	27	27	27	27
AIR3SQ	0.17488	-0.83126	0.41268	-0.00541	-0.23767	0.32393	0.37337	0.14629	0.42481	0.45625
	0.3830	0.0001	0.0324	0.9786	0.2326	0.0993	0.0551	0.4665	0.0272	0.0168
	27	27	27	27	27	27	27	27	27	27
AIR4SQ	0.97228	-0.84213	0.99991	0.91423	-0.98227	0.94380	0.97881	0.72936	0.98858	0.19520
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.3292
	27	27	27	27	27	27	27	27	27	27
SOL1SQ	0.30696	-0.89905	0.53255	0.13043	-0.36693	0.44246	0.49280	0.24434	0.54216	0.45389
	0.1194	0.0001	0.0043	0.5167	0.0597	0.0208	0.0090	0.2193	0.0035	0.0174
	27	27	27	27	27	27	27	27	27	27
SOL2SQ	0.69149	-1.00000	0.84851	0.55000	-0.73458	0.76583	0.81255	0.52764	0.84881	0.38730
	0.0001	0.0001	0.0001	0.0030	0.0001	0.0001	0.0001	0.0047	0.0001	0.0459
	27	27	27	27	27	27	27	27	27	27
SOL3SQ	0.51452	-0.97485	0.71039	0.35158	-0.56729	0.62180	0.67158	0.39773	0.71543	0.43115
	0.0060	0.0001	0.0001	0.0721	0.0020	0.0005	0.0001	0.0399	0.0001	0.0247
	27	27	27	27	27	27	27	27	27	27
SOL4SQ	-0.82212	0.15886	-0.65600	-0.91125	0.79093	-0.67852	-0.66707	-0.60442	-0.63490	0.17768
	0.0001	0.4287	0.0002	0.0001	0.0001	0.0001	0.0001	0.0009	0.0004	0.3753
	27	27	27	27	27	27	27	27	27	27
SOL5SQ	0.92099	-0.35697	0.79620	0.97612	-0.89090	0.80043	0.79925	0.68108	0.77630	-0.08815
	0.0001	0.0676	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.6620
	27	27	27	27	27	27	27	27	27	27
SOL6SQ	0.94173	-0.40971	0.82944	0.98693	-0.91497	0.82853	0.83022	0.69741	0.81002	-0.06243
	0.0001	0.0338	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.7570
	27	27	27	27	27	27	27	27	27	27
SOL7SQ	0.92768	-0.37329	0.80669	0.97978	-0.89860	0.80934	0.80904	0.68634	0.78692	-0.08028
	0.0001	0.0551	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.6906
	27	27	27	27	27	27	27	27	27	27

	BB4SQ	BFSQ	SBSQ	WSPSQ	SOLIN	SOLCA	SOLMG	SOLK	SOLNA	SOLP
SOLBSQ	0.67074 0.0001 27	0.07033 0.7274 27	0.46673 0.0141 27	0.79341 0.0001 27	-0.61919 0.0006 27	0.50855 0.0068 27	0.48620 0.0101 27	0.48068 0.0097 27	0.44535 0.0199 27	-0.26892 0.1751 27
BB1SQ	-0.34991 0.0736 27	0.91802 0.0001 27	-0.57048 0.0019 27	-0.17538 0.3816 27	0.40869 0.0343 27	-0.48031 0.0112 27	-0.53076 0.0044 27	-0.27616 0.1632 27	-0.57922 0.0016 27	-0.45122 0.0182 27
BB2SQ	-0.64536 0.0003 27	0.99797 0.0001 27	-0.81406 0.0001 27	-0.49715 0.0083 27	0.69139 0.0001 27	-0.72931 0.0001 27	-0.77712 0.0001 27	-0.49388 0.0088 27	-0.81569 0.0001 27	-0.40153 0.0379 27
BB3SQ	-0.52331 0.0051 27	0.97709 0.0001 27	-0.71760 0.0001 27	-0.36119 0.0642 27	0.57569 0.0017 27	-0.62918 0.0004 27	-0.67987 0.0001 27	-0.40421 0.0365 27	-0.72242 0.0001 27	-0.42958 0.0253 27
BB4SQ	1.00000 0.0000 27	-0.69269 0.0001 27	0.96901 0.0001 27	0.98363 0.0001 27	-0.99471 0.0001 27	0.93781 0.0001 27	0.95637 0.0001 27	0.74630 0.0001 27	0.95375 0.0001 27	0.09331 0.6434 27
BFSQ	-0.69269 0.0001 27	1.00000 0.0000 27	-0.84939 0.0001 27	-0.55138 0.0029 27	0.73570 0.0001 27	-0.76676 0.0001 27	-0.81345 0.0001 27	-0.52851 0.0046 27	-0.84965 0.0001 27	-0.38690 0.0462 27
SBSQ	0.96901 0.0001 27	-0.84939 0.0001 27	1.00000 0.0000 27	0.90863 0.0001 27	-0.97987 0.0001 27	0.94887 0.0001 27	0.97845 0.0001 27	0.72713 0.0001 27	0.98893 0.0001 27	0.20079 0.3153 27
WSPSQ	0.98363 0.0001 27	-0.55138 0.0029 27	0.90863 0.0001 27	1.00000 0.0000 27	-0.96676 0.0001 27	0.89319 0.0001 27	0.90299 0.0001 27	0.73119 0.0001 27	0.89091 0.0001 27	0.01126 0.9555 27
SOLIN	-0.99471 0.0001 27	0.73570 0.0001 27	-0.97987 0.0001 27	-0.96676 0.0001 27	1.00000 0.0000 27	-0.94397 0.0001 27	-0.96484 0.0001 27	-0.74189 0.0001 27	-0.96741 0.0001 27	-0.11658 0.5625 27
SOLCA	0.93781 0.0001 27	-0.76676 0.0001 27	0.94887 0.0001 27	0.89319 0.0001 27	-0.94397 0.0001 27	1.00000 0.0000 27	0.98192 0.0001 27	0.80096 0.0001 27	0.95996 0.0001 27	0.27985 0.1574 27
SOLMG	0.95637 0.0001 27	-0.81345 0.0001 27	0.97845 0.0001 27	0.90299 0.0001 27	-0.96484 0.0001 27	0.98192 0.0001 27	1.00000 0.0000 27	0.76010 0.0001 27	0.98468 0.0001 27	0.27913 0.1585 27
SOLK	0.74630 0.0001 27	-0.52851 0.0046 27	0.72713 0.0001 27	0.73119 0.0001 27	-0.74189 0.0001 27	0.80096 0.0001 27	0.76010 0.0001 27	1.00000 0.0000 27	0.74604 0.0001 27	0.09308 0.6442 27
SOLNA	0.95375 0.0001 27	-0.84965 0.0001 27	0.98893 0.0001 27	0.89091 0.0001 27	-0.96741 0.0001 27	0.95996 0.0001 27	0.98468 0.0001 27	0.74604 0.0001 27	1.00000 0.0000 27	0.25514 0.1990 27
SOLP	0.09331 0.6434 27	-0.38690 0.0462 27	0.20079 0.3153 27	0.01126 0.9555 27	-0.11658 0.5625 27	0.27985 0.1574 27	0.27913 0.1585 27	0.09308 0.6442 27	0.25514 0.1990 27	1.00000 0.0000 27

Appendix E. Oxalate content of cassava leaves from plants grown in irrigated plots

Site	Oxalate ($cmol\ kg^{-1}$ dry weight)		
	Total	Insoluble	Soluble*
Molokai	32.6	25.1	7.5
"	19.3	13.3	6.0
"	28.9	21.2	7.4
"	21.6	19.1	2.5
Waipio	34.3	38.4	-
"	29.8	32.0	-
"	23.3	24.7	1.9
"	24.4	22.5	1.9
Iole	35.9	32.8	2.1
"	18.9	13.2	5.7
"	19.9	17.2	2.7
"	23.1	21.0	2.1
"	21.8	18.5	3.3
"	18.2	12.6	5.6
Kukaiau	25.9	28.0	-
"	17.8	14.3	3.5
"	26.1	20.0	6.1
"	15.6	26.4	-
"	18.3	19.7	-
"	16.1	23.0	-

*Calculated from the difference between total and insoluble oxalate.

Appendix F. Correlation matrix of various plant compositions and soil and climatic factors in taro leaves from three experimental sites

	OX2	OX3	OX2_3	C_A	TOTALN	CA	MG	K	NA	SC	P	S	NO3
OX2	1.00000	-0.34731	0.42104	-0.19704	0.09385	-0.78808	0.28956	0.69308	-0.56753	-0.25365	0.75798	-0.27868	-0.14715
	0.0000	0.0303	0.0076	0.2292	0.5699	0.0001	0.0738	0.0001	0.0002	0.1192	0.0001	0.0858	0.3713
	39	39	39	39	39	39	39	39	39	39	39	39	39
OX3	-0.34731	1.00000	0.70435	0.38540	0.10987	0.43819	0.12856	-0.18969	0.35255	0.40520	-0.18937	0.17983	-0.07497
	0.0303	0.0000	0.0001	0.0154	0.5055	0.0053	0.4354	0.2474	0.0277	0.0105	0.2482	0.2733	0.6505
	39	39	39	39	39	39	39	39	39	39	39	39	39
OX2_3	0.42104	0.70435	1.00000	0.22362	0.17731	-0.17272	0.34354	0.34117	-0.08861	0.19992	0.39061	-0.03701	-0.18382
	0.0076	0.0001	0.0000	0.1712	0.2802	0.2930	0.0323	0.0335	0.5917	0.2224	0.0139	0.8230	0.2626
	39	39	39	39	39	39	39	39	39	39	39	39	39
C_A	-0.19704	0.38540	0.22362	1.00000	0.19320	0.53635	0.63420	0.16518	0.45080	0.96785	0.01419	0.15206	-0.03377
	0.2292	0.0154	0.1712	0.0000	0.2323	0.0004	0.0001	0.3084	0.0035	0.0001	0.9307	0.3489	0.8361
	39	39	39	40	40	40	40	40	40	40	40	40	40
TOTALN	0.09385	0.10987	0.17731	0.19320	1.00000	-0.01608	-0.16829	0.33655	0.20624	0.06914	-0.01802	-0.00382	0.17915
	0.5699	0.5055	0.2802	0.2323	0.0000	0.9216	0.2993	0.0337	0.2017	0.6716	0.9121	0.9813	0.2687
	39	39	39	40	40	40	40	40	40	40	40	40	40
CA	-0.78808	0.43819	-0.17272	0.53635	-0.01608	1.00000	-0.04170	-0.66308	0.62699	0.61434	-0.68466	0.51313	-0.09643
	0.0001	0.0053	0.2930	0.0004	0.9216	0.0000	0.7983	0.0001	0.0001	0.0001	0.0001	0.0007	0.5539
	39	39	39	40	40	40	40	40	40	40	40	40	40
MG	0.28956	0.12856	0.34354	0.63420	-0.16829	-0.04170	1.00000	0.30344	-0.12293	0.67199	0.45701	0.16383	-0.15108
	0.0738	0.4354	0.0323	0.0001	0.2993	0.7983	0.0000	0.0570	0.4498	0.0001	0.0030	0.3124	0.3521
	39	39	39	40	40	40	40	40	40	40	40	40	40
K	0.69308	-0.18969	0.34117	0.16518	0.33655	-0.66308	0.30344	1.00000	-0.23197	0.04108	0.73651	-0.51634	0.20093
	0.0001	0.2474	0.0335	0.3084	0.0337	0.0001	0.0570	0.0000	0.1498	0.8013	0.0001	0.0007	0.2137
	39	39	39	40	40	40	40	40	40	40	40	40	40

	OX2	OX3	OX2_3	C_A	TOTALN	CA	MG	K	NA	SC	P	S	NO
NA	-0.56753	0.35255	-0.08861	0.45080	0.20624	0.62699	-0.12293	-0.23197	1.00000	0.43290	-0.40386	0.02940	0.32426
	0.0002	0.0277	0.5917	0.0035	0.2017	0.0001	0.4498	0.1498	0.0000	0.0053	0.0098	0.8571	0.0412
	39	39	39	40	40	40	40	40	42	40	40	40	40
SC	-0.25365	0.40520	0.19992	0.96785	0.06914	0.61434	0.67199	0.04108	0.43290	1.00000	-0.03453	0.32319	-0.07021
	0.1192	0.0105	0.2224	0.0001	0.6716	0.0001	0.0001	0.8013	0.0053	0.0000	0.8325	0.0419	0.6668
	39	39	39	40	40	40	40	40	40	40	40	40	40
P	0.75798	-0.18937	0.39061	0.01419	-0.01802	-0.68466	0.45701	0.73651	-0.40386	-0.03453	1.00000	-0.42328	-0.02946
	0.0001	0.2482	0.0139	0.9307	0.9121	0.0001	0.0030	0.0001	0.0098	0.8325	0.0000	0.0065	0.8568
	39	39	39	40	40	40	40	40	40	40	40	40	40
S	-0.27868	0.17983	-0.03701	0.15206	-0.00382	0.51313	0.16383	-0.51634	0.02940	0.32319	-0.42328	1.00000	-0.37118
	0.0858	0.2733	0.8230	0.3489	0.9813	0.0007	0.3124	0.0007	0.8571	0.0419	0.0065	0.0000	0.0184
	39	39	39	40	40	40	40	40	40	40	40	40	40
NO3	-0.14715	-0.07487	-0.18382	-0.03377	0.17915	-0.09643	-0.15108	0.20098	0.32426	-0.07021	-0.02946	-0.37118	1.00000
	0.3713	0.6505	0.2626	0.8361	0.2687	0.5539	0.3521	0.2137	0.0412	0.6668	0.8568	0.0184	0.0000
	39	39	39	40	40	40	40	40	40	40	40	40	40
CL	-0.26532	0.12287	-0.08200	-0.07487	-0.50879	0.38444	0.15465	-0.54791	-0.06256	0.17465	-0.25245	0.71111	-0.28944
	0.1026	0.4562	0.6197	0.6461	0.0008	0.0143	0.3407	0.0003	0.7014	0.2811	0.1161	0.0001	0.0701
	39	39	39	40	40	40	40	40	40	40	40	40	40
SA	-0.23888	0.10590	-0.07839	-0.06682	-0.48035	0.34192	0.18838	-0.48221	-0.04361	0.18630	-0.19239	0.68808	-0.14662
	0.1430	0.5211	0.6352	0.6821	0.0017	0.0308	0.2444	0.0016	0.7893	0.2497	0.2343	0.0001	0.3666
	39	39	39	40	40	40	40	40	40	40	40	40	40
AIRMAX	0.59825	-0.29020	0.17216	-0.15882	-0.62805	-0.52379	0.47734	0.29849	-0.52391	-0.09614	0.64363	-0.10528	-0.16145
	0.0001	0.0731	0.2946	0.3277	0.0001	0.0005	0.0018	0.0614	0.0004	0.5551	0.0001	0.5179	0.3196
	39	39	39	40	40	40	40	40	42	40	40	40	40
AIRMIN	0.27176	-0.27336	-0.05869	-0.25199	-0.82693	-0.26240	0.24726	-0.04530	-0.44164	-0.14683	0.33282	-0.00747	-0.15800
	0.0942	0.0922	0.7227	0.1167	0.0001	0.1019	0.1240	0.7813	0.0034	0.3659	0.0359	0.9635	0.3302
	39	39	39	40	40	40	40	40	42	40	40	40	40
AIRAVE	0.51682	-0.29260	0.10820	-0.19070	-0.70339	-0.45887	0.42060	0.20323	-0.51193	-0.11373	0.56695	-0.07869	-0.16450
	0.0008	0.0707	0.5121	0.2385	0.0001	0.0029	0.0069	0.2085	0.0005	0.4847	0.0001	0.6293	0.3104
	39	39	39	40	40	40	40	40	42	40	40	40	40
RHMAX	-0.07867	0.23960	0.17221	0.27684	0.85443	0.10704	-0.10907	0.21514	0.36476	0.15949	-0.14626	-0.04265	0.14230
	0.6340	0.1418	0.2945	0.0837	0.0001	0.5109	0.5029	0.1825	0.0175	0.3256	0.3678	0.7938	0.3811
	39	39	39	40	40	40	40	40	42	40	40	40	40
RHMIN	-0.69774	0.27589	-0.26131	0.10474	0.49064	0.60189	-0.54484	-0.43086	0.52172	0.06597	-0.73490	0.14140	0.15074
	0.0001	0.0891	0.1081	0.5201	0.0013	0.0001	0.0003	0.0055	0.0004	0.6859	0.0001	0.3841	0.3532
	39	39	39	40	40	40	40	40	42	40	40	40	40
RHAVE	-0.56263	0.29201	-0.14345	0.17377	0.66401	0.49545	-0.45261	-0.25573	0.51973	0.10441	-0.61021	0.09380	0.16324
	0.0002	0.0713	0.3836	0.2836	0.0001	0.0012	0.0034	0.1112	0.0004	0.5214	0.0001	0.5665	0.3142
	39	39	39	40	40	40	40	40	42	40	40	40	40

	OX2	OX3	OX2_3	C_A	TOTALN	CA	MG	K	NA	SC	P	S	NO3
TSMAX	0.07041	-0.23786	-0.17677	-0.27753	-0.85451	-0.10037	0.10312	-0.22201	-0.36113	-0.15983	0.13822	0.04471	-0.14146
	0.6702	0.1448	0.2817	0.0829	0.0001	0.5377	0.5266	0.1686	0.0188	0.3246	0.3950	0.7841	0.3839
	39	39	39	40	40	40	40	40	42	40	40	40	40
TSMIN	0.30314	-0.27748	-0.03892	-0.24626	-0.81742	-0.28759	0.26958	-0.01585	-0.45260	-0.14391	0.36297	-0.01604	-0.15979
	0.0607	0.0872	0.8140	0.1256	0.0001	0.0720	0.0925	0.9227	0.0026	0.3760	0.0213	0.9218	0.3247
	39	39	39	40	40	40	40	40	42	40	40	40	40
TSAVE	0.17239	-0.25771	-0.11877	-0.26690	-0.84740	-0.18255	0.17633	-0.13501	-0.40401	-0.15456	0.23706	0.01885	-0.15089
	0.2940	0.1132	0.4714	0.0959	0.0001	0.2596	0.2764	0.4062	0.0080	0.3410	0.1408	0.9081	0.3527
	39	39	39	40	40	40	40	40	42	40	40	40	40
SSMAX	0.71984	-0.26977	0.28397	-0.08879	-0.44829	-0.61880	0.55925	0.46432	-0.51660	-0.05701	0.75441	-0.15033	-0.14652
	0.0001	0.0967	0.0798	0.5859	0.0037	0.0001	0.0002	0.0025	0.0005	0.7268	0.0001	0.3545	0.3670
	39	39	39	40	40	40	40	40	42	40	40	40	40
SSMIN	0.70116	-0.27505	0.26472	-0.10240	-0.48449	-0.60452	0.54709	0.43591	-0.52109	-0.06466	0.73795	-0.14275	-0.15015
	0.0001	0.0901	0.1034	0.5295	0.0015	0.0001	0.0003	0.0049	0.0004	0.6918	0.0001	0.3796	0.3551
	39	39	39	40	40	40	40	40	42	40	40	40	40
SSAVE	0.71126	-0.27233	0.27500	-0.09523	-0.46549	-0.61227	0.55370	0.45108	-0.51889	-0.06063	0.74689	-0.14680	-0.14828
	0.0001	0.0935	0.0902	0.5589	0.0025	0.0001	0.0002	0.0035	0.0004	0.7101	0.0001	0.3660	0.3612
	39	39	39	40	40	40	40	40	42	40	40	40	40
RF	-0.72193	0.26910	-0.28620	0.08716	0.44394	0.62038	-0.56059	-0.46759	0.51597	0.05610	-0.75622	0.15120	0.14607
	0.0001	0.0976	0.0773	0.5928	0.0041	0.0001	0.0002	0.0024	0.0005	0.7310	0.0001	0.3517	0.3685
	39	39	39	40	40	40	40	40	42	40	40	40	40
RAD	0.62273	-0.28813	0.19270	-0.14745	-0.60004	-0.54319	0.49420	0.32904	-0.52558	-0.08982	0.66642	-0.11371	-0.15971
	0.0001	0.0753	0.2399	0.3639	0.0001	0.0003	0.0012	0.0382	0.0004	0.5815	0.0001	0.4848	0.3249
	39	39	39	40	40	40	40	40	42	40	40	40	40
WIND	-0.54118	0.29251	-0.12673	0.18199	0.68332	0.47834	-0.43765	-0.23084	0.51638	0.10894	-0.59000	0.08644	0.16397
	0.0004	0.0708	0.4420	0.2611	0.0001	0.0018	0.0047	0.1518	0.0005	0.5034	0.0001	0.5959	0.3120
	39	39	39	40	40	40	40	40	42	40	40	40	40
SOLCA	0.70201	-0.05770	0.47560	0.18049	0.36959	-0.55900	0.49291	0.71402	-0.17423	0.09768	0.66580	-0.20425	-0.01576
	0.0001	0.7272	0.0022	0.2651	0.0189	0.0002	0.0012	0.0001	0.2698	0.5487	0.0001	0.2061	0.9231
	39	39	39	40	40	40	40	40	42	40	40	40	40
SOLMG	0.73996	-0.26255	0.30618	-0.07209	-0.40319	-0.63388	0.57200	0.49694	-0.50928	-0.04761	0.77166	-0.15895	-0.14166
	0.0001	0.1064	0.0580	0.6584	0.0099	0.0001	0.0001	0.0011	0.0006	0.7705	0.0001	0.3273	0.3832
	39	39	39	40	40	40	40	40	42	40	40	40	40
SOLK	0.71605	-0.27093	0.27998	-0.09168	-0.45602	-0.61592	0.55681	0.45842	-0.51766	-0.05864	0.75110	-0.14876	-0.14732
	0.0001	0.0953	0.0843	0.5737	0.0031	0.0001	0.0002	0.0029	0.0004	0.7193	0.0001	0.3596	0.3643
	39	39	39	40	40	40	40	40	42	40	40	40	40
SOLNA	0.67474	-0.28082	0.23914	-0.11939	-0.52888	-0.58406	0.52954	0.39804	-0.52473	-0.07418	0.71421	-0.13254	-0.15422
	0.0001	0.0833	0.1426	0.4631	0.0005	0.0001	0.0004	0.0110	0.0004	0.6492	0.0001	0.4149	0.3420
	39	39	39	40	40	40	40	40	42	40	40	40	40

	OX2	OX3	OX2_3	C_A	TOTALN	CA	MG	K	NA	SC	P	S	NO3
SOLP	-0.76182	0.10886	-0.47139	-0.13650	-0.22105	0.61884	-0.54867	-0.71892	0.26502	-0.07191	-0.74089	0.20950	0.04577
	0.0001	0.5095	0.0025	0.4010	0.1705	0.0001	0.0002	0.0001	0.0899	0.6592	0.0001	0.1945	0.7792
	39	39	39	40	40	40	40	40	42	40	40	40	40

	CL	SA	AIRMAX	AIRMIN	AIRAVE	RHMAX	RHMIN	RHAVE	TSMAX	TSMIN	TSAVE	SSMAX	SSMIN
OX2	-0.26532	-0.23888	0.59825	0.27176	0.51682	-0.07867	-0.69774	-0.56263	0.07041	0.30314	0.17239	0.71984	0.70116
	0.1026	0.1430	0.0001	0.0942	0.0008	0.6340	0.0001	0.0002	0.6702	0.0607	0.2940	0.0001	0.0001
	39	39	39	39	39	39	39	39	39	39	39	39	39
OX3	0.12287	0.10590	-0.29020	-0.27336	-0.29260	0.23960	0.27589	0.29201	-0.23786	-0.27748	-0.25771	-0.26977	-0.27505
	0.4562	0.5211	0.0731	0.0922	0.0707	0.1418	0.0891	0.0713	0.1448	0.0872	0.1132	0.0967	0.0901
	39	39	39	39	39	39	39	39	39	39	39	39	39
OX2_3	-0.08200	-0.07839	0.17216	-0.05869	0.10820	0.17221	-0.26131	-0.14345	-0.17677	-0.03892	-0.11877	0.28397	0.26472
	0.6197	0.6352	0.2946	0.7227	0.5121	0.2945	0.1081	0.3836	0.2817	0.8140	0.4714	0.0798	0.1034
	39	39	39	39	39	39	39	39	39	39	39	39	39
C_A	-0.07487	-0.06682	-0.15882	-0.25199	-0.19070	0.27684	0.10474	0.17377	-0.27753	-0.24626	-0.26690	-0.08879	-0.10240
	0.6461	0.6821	0.3277	0.1167	0.2385	0.0837	0.5201	0.2836	0.0829	0.1256	0.0959	0.5859	0.5295
	40	40	40	40	40	40	40	40	40	40	40	40	40
TOTALN	-0.50879	-0.48035	-0.62805	-0.82693	-0.70339	0.85443	0.49064	0.66401	-0.85451	-0.81742	-0.84740	-0.44829	-0.48449
	0.0008	0.0017	0.0001	0.0001	0.0001	0.0001	0.0013	0.0001	0.0001	0.0001	0.0001	0.0037	0.0015
	40	40	40	40	40	40	40	40	40	40	40	40	40
CA	0.38444	0.34192	-0.52379	-0.26240	-0.45887	0.10704	0.60189	0.49545	-0.10037	-0.28759	-0.18255	-0.61880	-0.60452
	0.0143	0.0308	0.0005	0.1019	0.0029	0.5109	0.0001	0.0012	0.5377	0.0720	0.2596	0.0001	0.0001
	40	40	40	40	40	40	40	40	40	40	40	40	40
MG	0.15465	0.18838	0.47734	0.24726	0.42060	-0.10907	-0.54484	-0.45261	0.10312	0.26958	0.17633	0.55925	0.54709
	0.3407	0.2444	0.0018	0.1240	0.0069	0.5029	0.0003	0.0034	0.5266	0.0925	0.2764	0.0002	0.0003
	40	40	40	40	40	40	40	40	40	40	40	40	40
K	-0.54791	-0.48221	0.29849	-0.04530	0.20323	0.21514	-0.43086	-0.25573	-0.22201	-0.01585	-0.13501	0.46432	0.43591
	0.0003	0.0016	0.0614	0.7813	0.2085	0.1825	0.0055	0.1112	0.1686	0.9227	0.4062	0.0025	0.0049
	40	40	40	40	40	40	40	40	40	40	40	40	40
NA	-0.06256	-0.04361	-0.52391	-0.44164	-0.51193	0.36476	0.52172	0.51973	-0.36113	-0.45260	-0.40401	-0.51660	-0.52109
	0.7014	0.7893	0.0004	0.0034	0.0005	0.0175	0.0004	0.0004	0.0188	0.0026	0.0080	0.0005	0.0004
	40	40	42	42	42	42	42	42	42	42	42	42	42
SC	0.17465	0.18630	-0.09614	-0.14683	-0.11373	0.15949	0.06597	0.10441	-0.15983	-0.14381	-0.15456	-0.05701	-0.06466
	0.2811	0.2497	0.5551	0.3659	0.4847	0.3256	0.6859	0.5214	0.3246	0.3760	0.3410	0.7268	0.6918
	40	40	40	40	40	40	40	40	40	40	40	40	40
P	-0.25245	-0.19239	0.64363	0.33282	0.56695	-0.14626	-0.73490	-0.61021	0.13822	0.36297	0.23706	0.75441	0.73795
	0.1161	0.2343	0.0001	0.0359	0.0001	0.3678	0.0001	0.0001	0.3950	0.0213	0.1408	0.0001	0.0001
	40	40	40	40	40	40	40	40	40	40	40	40	40
S	0.71111	0.68808	-0.10528	-0.00747	-0.07869	-0.04265	0.14140	0.09340	0.04471	-0.01604	0.01885	-0.15033	-0.14275
	0.0001	0.0001	0.5179	0.9635	0.6293	0.7938	0.3841	0.5665	0.7841	0.9218	0.9081	0.3545	0.3796
	40	40	40	40	40	40	40	40	40	40	40	40	40

	CL	SA	AIRMAX	AIRMIN	AIRAVE	RHMAX	RHMIN	RHAVE	TSMAX	TSMIN	TSAVE	SSMAX	SSMIN
NO3	-0.28944	-0.14662	-0.16145	-0.15800	-0.16450	0.14230	0.15074	0.16324	-0.14146	-0.15979	-0.15089	-0.14652	-0.15015
	0.0701	0.3666	0.3196	0.3302	0.3104	0.3811	0.3532	0.3142	0.3839	0.3247	0.3527	0.3670	0.3551
	40	40	40	40	40	40	40	40	40	40	40	40	40
CL	1.00000	0.98524	0.21070	0.39578	0.27136	-0.45439	-0.11122	-0.23892	0.45628	0.38341	0.42949	0.08254	0.10700
	0.0000	0.0001	0.1919	0.0115	0.0903	0.0032	0.4945	0.1376	0.0031	0.0146	0.0057	0.6126	0.5111
	40	40	40	40	40	40	40	40	40	40	40	40	40
SA	0.98524	1.00000	0.23901	0.40183	0.29374	-0.44866	-0.14742	-0.26459	0.45006	0.39146	0.42939	0.12065	0.14349
	0.0001	0.0000	0.1375	0.0102	0.0658	0.0037	0.3640	0.0990	0.0036	0.0125	0.0057	0.4583	0.3771
	40	40	40	40	40	40	40	40	40	40	40	40	40
AIRMAX	0.21070	0.23901	1.00000	0.88512	0.98994	-0.75557	-0.97614	-0.99789	0.74929	0.90284	0.82265	0.96097	0.97413
	0.1919	0.1375	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	40	40	42	42	42	42	42	42	42	42	42	42	42
AIRMIN	0.39578	0.40183	0.88512	1.00000	0.94205	-0.97361	-0.76296	-0.91344	0.97139	0.99922	0.99272	0.72183	0.75707
	0.0115	0.0102	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	40	40	42	42	42	42	42	42	42	42	42	42	42
AIRAVE	0.27136	0.29374	0.98994	0.94205	1.00000	-0.84064	-0.93561	-0.99703	0.83544	0.95459	0.89480	0.91217	0.93237
	0.0903	0.0658	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	40	40	42	42	42	42	42	42	42	42	42	42	42
RHMAX	-0.45439	-0.44866	-0.75557	-0.97361	-0.84064	1.00000	0.59530	0.79647	-0.99995	-0.96382	-0.99401	-0.54485	-0.58800
	0.0032	0.0037	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001
	40	40	42	42	42	42	42	42	42	42	42	42	42
RHMIN	-0.11122	-0.14742	-0.97614	-0.76296	-0.93561	0.59530	1.00000	0.96000	-0.58762	-0.78793	-0.67957	-0.99811	-0.99996
	0.4945	0.3640	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	40	40	42	42	42	42	42	42	42	42	42	42	42
RHAVE	-0.23892	-0.26459	-0.99789	-0.91344	-0.99703	0.79647	0.96000	1.00000	-0.79067	-0.92883	-0.85779	-0.94100	-0.95743
	0.1376	0.0990	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001
	40	40	42	42	42	42	42	42	42	42	42	42	42
TSMAX	0.45628	0.45006	0.74929	0.97139	0.83544	-0.99995	-0.58762	-0.79067	1.00000	0.96124	0.99292	0.53683	0.58026
	0.0031	0.0036	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0002	0.0001
	40	40	42	42	42	42	42	42	42	42	42	42	42
TSMIN	0.38341	0.39146	0.90284	0.99922	0.95459	-0.96382	-0.78793	-0.92883	0.96124	1.00000	0.98718	0.74865	0.78232
	0.0146	0.0125	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001
	40	40	42	42	42	42	42	42	42	42	42	42	42
TSAVE	0.42949	0.42939	0.82265	0.99272	0.89480	-0.99401	-0.67957	-0.85779	0.99292	0.98718	1.00000	0.63325	0.67299
	0.0057	0.0057	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001
	40	40	42	42	42	42	42	42	42	42	42	42	42
SSMAX	0.08254	0.12065	0.96097	0.72183	0.91217	-0.54485	-0.99811	-0.94100	0.53683	0.74865	0.63325	1.00000	0.99863
	0.6126	0.4583	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0002	0.0001	0.0001	0.0000	0.0001
	40	40	42	42	42	42	42	42	42	42	42	42	42

	CL	SA	AIRMAX	AIRMIN	AIRAVE	RHMAX	RHMIN	RHAVE	TSMAX	TSMIN	TSAVE	SSMAX	SSMIN
SSMIN	0.10700 0.5111 40	0.14349 0.3771 40	0.97413 0.0001 42	0.75707 0.0001 42	0.93237 0.0001 42	-0.58800 0.0001 42	-0.99996 0.0001 42	-0.95743 0.0001 42	0.58026 0.0001 42	0.78232 0.0001 42	0.67289 0.0001 42	0.99863 0.0001 42	1.00000 0.0000 42
SSAVE	0.09409 0.5636 40	0.13145 0.4188 40	0.96751 0.0001 42	0.73870 0.0001 42	0.92201 0.0001 42	-0.56539 0.0001 42	-0.99933 0.0001 42	-0.94907 0.0001 42	0.55750 0.0001 42	0.76479 0.0001 42	0.65217 0.0001 42	0.99970 0.0001 42	0.99962 0.0001 42
RF	-0.07964 0.6252 40	-0.11793 0.4686 40	-0.95924 0.0001 42	-0.71753 0.0001 42	-0.90961 0.0001 42	0.53964 0.0002 42	0.99771 0.0001 42	0.93889 0.0001 42	-0.53159 0.0003 42	-0.74452 0.0001 42	-0.62844 0.0001 42	-0.99998 0.0001 42	-0.99829 0.0001 42
RAD	0.18946 0.2417 40	0.21963 0.1733 40	0.99886 0.0001 42	0.86187 0.0001 42	0.98205 0.0001 42	-0.72339 0.0001 42	-0.98540 0.0001 42	-0.99365 0.0001 42	0.71678 0.0001 42	0.88125 0.0001 42	0.79453 0.0001 42	0.97310 0.0001 42	0.98382 0.0001 42
WIND	-0.25460 0.1129 40	-0.27871 0.0816 40	-0.99483 0.0001 42	-0.92782 0.0001 42	-0.99919 0.0001 42	0.81821 0.0001 42	0.94903 0.0001 42	0.99932 0.0001 42	-0.81269 0.0001 42	-0.94185 0.0001 42	-0.87615 0.0001 42	-0.92790 0.0001 42	-0.94614 0.0001 42
SOLCA	-0.36423 0.0209 40	-0.31752 0.0459 40	0.24470 0.1183 42	-0.23461 0.1348 42	0.10508 0.5078 42	0.45026 0.0028 42	-0.44940 0.0028 42	-0.18130 0.2505 42	-0.45875 0.0022 42	-0.19598 0.2136 42	-0.34996 0.0231 42	0.50340 0.0007 42	0.45748 0.0023 42
SOLMG	0.05281 0.7462 40	0.09274 0.5692 40	0.94153 0.0001 42	0.67659 0.0001 42	0.88441 0.0001 42	-0.49069 0.0010 42	-0.99223 0.0001 42	-0.91770 0.0001 42	0.48236 0.0012 42	0.70519 0.0001 42	0.58300 0.0001 42	0.99800 0.0001 42	0.99331 0.0001 42
SOLK	0.08772 0.5904 40	0.12549 0.4404 40	0.96397 0.0001 42	0.72944 0.0001 42	0.91664 0.0001 42	-0.55409 0.0001 42	-0.99873 0.0001 42	-0.94469 0.0001 42	0.54613 0.0002 42	0.75593 0.0001 42	0.64177 0.0001 42	0.99994 0.0001 42	0.99915 0.0001 42
SOLNA	0.13782 0.3964 40	0.17211 0.2883 40	0.98700 0.0001 42	0.79882 0.0001 42	0.95434 0.0001 42	-0.64046 0.0001 42	-0.99835 0.0001 42	-0.97450 0.0001 42	0.63311 0.0001 42	0.82199 0.0001 42	0.72058 0.0001 42	0.99294 0.0001 42	0.99779 0.0001 42
SOLP	0.29666 0.0631 40	0.24793 0.1230 40	-0.42378 0.0052 42	0.04641 0.7704 42	-0.29139 0.0612 42	-0.27314 0.0801 42	0.61034 0.0001 42	0.36414 0.0178 42	0.28230 0.0701 42	0.00686 0.9656 42	0.16635 0.2924 42	-0.65782 0.0001 42	-0.61750 0.0001 42

	SSAVE	RF	RAD	WIND	SOLCA	SOLMG	SOLK	SOLNA	SOLP
OX2	0.71126 0.0001 39	-0.72193 0.0001 39	0.62273 0.0001 39	-0.54118 0.0004 39	0.70201 0.0001 39	0.73996 0.0001 39	0.71605 0.0001 39	0.67474 0.0001 39	-0.76182 0.0001 39
OX3	-0.27233 0.0935 39	0.26910 0.0976 39	-0.28813 0.0753 39	0.29251 0.0708 39	-0.05770 0.7272 39	-0.26255 0.1064 39	-0.27093 0.0953 39	-0.28082 0.0833 39	0.10886 0.5095 39
OX2_3	0.27500 0.0902 39	-0.28620 0.0773 39	0.19270 0.2399 39	-0.12673 0.4420 39	0.47560 0.0022 39	0.30618 0.0580 39	0.27998 0.0843 39	0.23914 0.1426 39	-0.47139 0.0025 39

	SSAVE	EP	RAD	WIND	SOLCA	SOLMG	SOLK	SOLNA	SOLP
C_A	-0.09523	0.08716	-0.14745	0.18199	0.18049	-0.07209	-0.09168	-0.11939	-0.13650
	0.5589	0.5928	0.3639	0.2611	0.2651	0.6584	0.5737	0.4631	0.4010
	40	40	40	40	40	40	40	40	40
TOTALN	-0.46549	0.44394	-0.60004	0.68332	0.36959	-0.40319	-0.45602	-0.52888	-0.22105
	0.0025	0.0041	0.0001	0.0001	0.0189	0.0099	0.0031	0.0005	0.1705
	40	40	40	40	40	40	40	40	40
CA	-0.61227	0.62038	-0.54319	0.47834	-0.55900	-0.63388	-0.61592	-0.58406	0.61884
	0.0001	0.0001	0.0003	0.0018	0.0002	0.0001	0.0001	0.0001	0.0001
	40	40	40	40	40	40	40	40	40
MG	0.55370	-0.56059	0.49420	-0.43765	0.49291	0.57200	0.55681	0.52954	-0.54867
	0.0002	0.0002	0.0012	0.0047	0.0012	0.0001	0.0002	0.0004	0.0002
	40	40	40	40	40	40	40	40	40
K	0.45108	-0.46759	0.32904	-0.23084	0.71402	0.49694	0.45842	0.39804	-0.71892
	0.0035	0.0024	0.0382	0.1518	0.0001	0.0011	0.0029	0.0110	0.0001
	40	40	40	40	40	40	40	40	40
NA	-0.51889	0.51597	-0.52558	0.51638	-0.17423	-0.50928	-0.51766	-0.52473	0.26502
	0.0004	0.0005	0.0004	0.0005	0.2698	0.0006	0.0004	0.0004	0.0899
	42	42	42	42	42	42	42	42	42
SC	-0.06063	0.05610	-0.08982	0.10894	0.09768	-0.04761	-0.05864	-0.07418	-0.07191
	0.7101	0.7310	0.5815	0.5034	0.5487	0.7705	0.7193	0.6492	0.6592
	40	40	40	40	40	40	40	40	40
P	0.74689	-0.75622	0.66642	-0.59000	0.66580	0.77166	0.75110	0.71421	-0.74089
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	40	40	40	40	40	40	40	40	40
S	-0.14680	0.15120	-0.11371	0.08644	-0.20425	-0.15895	-0.14876	-0.13254	0.20950
	0.3660	0.3517	0.4848	0.5959	0.2061	0.3273	0.3596	0.4149	0.1945
	40	40	40	40	40	40	40	40	40
NO3	-0.14828	0.14607	-0.15971	0.16397	-0.01576	-0.14166	-0.14732	-0.15422	0.04577
	0.3612	0.3685	0.3249	0.3120	0.9231	0.3832	0.3643	0.3420	0.7792
	40	40	40	40	40	40	40	40	40
CL	0.09409	-0.07964	0.18946	-0.25460	-0.36423	0.05281	0.08772	0.13782	0.29666
	0.5636	0.6252	0.2417	0.1129	0.0209	0.7462	0.5904	0.3964	0.0631
	40	40	40	40	40	40	40	40	40
SA	0.13145	-0.11793	0.21963	-0.27871	-0.31752	0.09274	0.12549	0.17211	0.24793
	0.4188	0.4686	0.1733	0.0816	0.0459	0.5692	0.4404	0.2883	0.1230
	40	40	40	40	40	40	40	40	40
AIRMAX	0.96751	-0.95924	0.99886	-0.99483	0.24470	0.94153	0.96397	0.98700	-0.42378
	0.0001	0.0001	0.0001	0.0001	0.1183	0.0001	0.0001	0.0001	0.0052
	42	42	42	42	42	42	42	42	42

	SSAVE	RF	RAD	WIND	SOLCA	SOLMG	SOLK	SOLNA	SOLP
AIRMIN	0.73870	-0.71753	0.86187	-0.92782	-0.23461	0.67659	0.72944	0.79882	0.04641
	0.0001	0.0001	0.0001	0.0001	0.1348	0.0001	0.0001	0.0001	0.7704
	42	42	42	42	42	42	42	42	42
AIRAVE	0.92201	-0.90961	0.98205	-0.99919	0.10508	0.88441	0.91664	0.95434	-0.29139
	0.0001	0.0001	0.0001	0.0001	0.5078	0.0001	0.0001	0.0001	0.0612
	42	42	42	42	42	42	42	42	42
RHMAX	-0.56539	0.53964	-0.72339	0.81821	0.45026	-0.49069	-0.55409	-0.64046	-0.27314
	0.0001	0.0002	0.0001	0.0001	0.0028	0.0010	0.0001	0.0001	0.0801
	42	42	42	42	42	42	42	42	42
RHMIN	-0.99933	0.99771	-0.98540	0.94903	-0.44940	-0.99223	-0.99873	-0.99835	0.61034
	0.0001	0.0001	0.0001	0.0001	0.0028	0.0001	0.0001	0.0001	0.0001
	42	42	42	42	42	42	42	42	42
RHAVE	-0.94907	0.93889	-0.99365	0.99932	-0.18130	-0.91770	-0.94469	-0.97450	0.36414
	0.0001	0.0001	0.0001	0.0001	0.2505	0.0001	0.0001	0.0001	0.0178
	42	42	42	42	42	42	42	42	42
TSMAX	0.55750	-0.53159	0.71678	-0.81269	-0.45875	0.48236	0.54613	0.63311	0.28230
	0.0001	0.0003	0.0001	0.0001	0.0022	0.0012	0.0002	0.0001	0.0701
	42	42	42	42	42	42	42	42	42
TSMIN	0.76479	-0.74452	0.88125	-0.94185	-0.19598	0.70519	0.75593	0.82199	0.00686
	0.0001	0.0001	0.0001	0.0001	0.2136	0.0001	0.0001	0.0001	0.9656
	42	42	42	42	42	42	42	42	42
TSAVE	0.65217	-0.62844	0.79453	-0.87615	-0.34996	0.58300	0.64177	0.72058	0.16635
	0.0001	0.0001	0.0001	0.0001	0.0231	0.0001	0.0001	0.0001	0.2924
	42	42	42	42	42	42	42	42	42
SSMAX	0.99970	-0.99998	0.97310	-0.92790	0.50340	0.99800	0.99994	0.99294	-0.65782
	0.0001	0.0001	0.0001	0.0001	0.0007	0.0001	0.0001	0.0001	0.0001
	42	42	42	42	42	42	42	42	42
SSMIN	0.99962	-0.99829	0.98382	-0.94614	0.45748	0.99331	0.99915	0.99779	-0.61750
	0.0001	0.0001	0.0001	0.0001	0.0023	0.0001	0.0001	0.0001	0.0001
	42	42	42	42	42	42	42	42	42
SSAVE	1.00000	-0.99952	0.97849	-0.93682	0.48191	0.99613	0.99991	0.99557	-0.63903
	0.0000	0.0001	0.0001	0.0001	0.0012	0.0001	0.0001	0.0001	0.0001
	42	42	42	42	42	42	42	42	42
RF	-0.99952	1.00000	-0.97165	0.92557	-0.50874	-0.99837	-0.99985	-0.99219	0.66248
	0.0001	0.0000	0.0001	0.0001	0.0006	0.0001	0.0001	0.0001	0.0001
	42	42	42	42	42	42	42	42	42
RAD	0.97849	-0.97165	1.00000	-0.98883	0.29077	0.95656	0.97558	0.99355	-0.46659
	0.0001	0.0001	0.0000	0.0001	0.0617	0.0001	0.0001	0.0001	0.0018
	42	42	42	42	42	42	42	42	42

	SSAVE	RP	RAD	WIND	SOLCA	SOLMG	SOLK	SOLNA	SOLP
WIND	-0.93682	0.92557	-0.98883	1.00000	-0.14494	-0.90244	-0.93196	-0.96557	0.32958
	0.0001	0.0001	0.0001	0.0000	0.3597	0.0001	0.0001	0.0001	0.0331
	42	42	42	42	42	42	42	42	42
SOLCA	0.48191	-0.50874	0.29077	-0.14494	1.00000	0.55707	0.49381	0.39736	-0.98193
	0.0012	0.0006	0.0617	0.3597	0.0000	0.0001	0.0009	0.0092	0.0001
	42	42	42	42	42	42	42	42	42
SOLMG	0.99613	-0.99837	0.95656	-0.90244	0.55707	1.00000	0.99723	0.98344	-0.70417
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001
	42	42	42	42	42	42	42	42	42
SOLK	0.99991	-0.99985	0.97558	-0.93196	0.49381	0.99723	1.00000	0.99419	-0.64946
	0.0001	0.0001	0.0001	0.0001	0.0009	0.0001	0.0000	0.0001	0.0001
	42	42	42	42	42	42	42	42	42
SOLNA	0.99557	-0.99219	0.99355	-0.96557	0.39736	0.98344	0.99419	1.00000	-0.56385
	0.0001	0.0001	0.0001	0.0001	0.0092	0.0001	0.0001	0.0000	0.0001
	42	42	42	42	42	42	42	42	42
SOLP	-0.63903	0.66248	-0.46659	0.32958	-0.98193	-0.70417	-0.64946	-0.56385	1.00000
	0.0001	0.0001	0.0018	0.0331	0.0001	0.0001	0.0001	0.0001	0.0000
	42	42	42	42	42	42	42	42	42

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